Online ISSN : 2249-4596
Print ISSN : 0975-5861
DOI : 10.17406/GJRE

Global Journal

of Researches in Engineering: E

Civil and Structural Engineering

Analysis of Sustainable Indicators

Surfaces on Trapezium-Curved Plans

Highlights

Properties of Geopolymer Bricks

Utilization of the Three-Dimensional

Discovering Thoughts, Inventing Future

VOLUME 20 ISSUE 2 VERSION 1.0

Global Journal of Researches in Engineering: E
Civil and Structural Engineering

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN):
USA Tax ID: 98-0673427

Global Journals Inc.

*(A Delaware USA Incorporation with "Good Standing"; **Reg. Number: 0423089**)*

Sponsors: *Open Association of Research Society*
Open Scientific Standards

Publisher's Headquarters office

Global Journals® Headquarters
945th Concord Streets,
Framingham Massachusetts Pin: 01701,
United States of America
USA Toll Free: +001-888-839-7392
USA Toll Free Fax: +001-888-839-7392

Offset Typesetting

Global Journals Incorporated
2nd, Lansdowne, Lansdowne Rd., Croydon-Surrey,
Pin: CR9 2ER, United Kingdom

Packaging & Continental Dispatching

Global Journals Pvt Ltd
E-3130 Sudama Nagar, Near Gopur Square,
Indore, M.P., Pin:452009, India

Find a correspondence nodal officer near you

To find nodal officer of your country, please email us at *local@globaljournals.org*

eContacts

Press Inquiries: *press@globaljournals.org*
Investor Inquiries: *investors@globaljournals.org*
Technical Support: *technology@globaljournals.org*
Media & Releases: *media@globaljournals.org*

Pricing (Excluding Air Parcel Charges):

Yearly Subscription (Personal & Institutional)
250 USD (B/W) & 350 USD (Color)

Prof. (LU), (UoS) Dr. Miklas Scholz

Cand Ing, BEng (equiv), PgC, MSc, Ph.D., CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA, VINNOVA Fellow, Marie Curie Senior, Fellow, Chair in Civil Engineering (UoS) Wetland Systems, Sustainable Drainage, and Water Quality

Dr. Kitipong Jaojaruek

B. Eng, M. Eng, D. Eng (Energy Technology, Asian Institute of Technology). Kasetsart University Kamphaeng Saen (KPS) Campus Energy Research Laboratory of Mechanical Engineering

Dr. Yudong Zhang

B.S., M.S., Ph.D. Signal and Information Processing, Southeast University Professor School of Information Science and Technology at Nanjing Normal University, China

Dr. Burcin Becerik-Gerber

University of Southern Californi Ph.D. in Civil Engineering Ddes, from Harvard University M.S. from University of California, Berkeley M.S. from Istanbul, Technical University

Dr. Minghua He

Department of Civil Engineering Tsinghua University Beijing, 100084, China

Hiroshi Sekimoto

Professor Emeritus Tokyo Institute of Technology Japan Ph.D., University of California Berkeley

Dr. Philip G. Moscoso

Technology and Operations Management IESE Business School, University of Navarra Ph.D. in Industrial Engineering and Management, ETH Zurich M.Sc. in Chemical Engineering, ETH Zurich, Spain

Dr. Shaoping Xiao

BS, MS Ph.D. Mechanical Engineering, Northwestern University The University of Iowa, Department of Mechanical and Industrial Engineering Center for Computer-Aided Design

Dr. Stefano Mariani

Associate Professor, Structural Mechanics, Department of Civil and Environmental Engineering, Ph.D., in Structural Engineering Polytechnic University of Milan Italy

Dr. A. Stegou-Sagia

Ph.D., Mechanical Engineering, Environmental Engineering School of Mechanical Engineering, National Technical University of Athens, Greece

Dr. Ciprian Lapusan

Ph. D in Mechanical Engineering Technical University of Cluj-Napoca Cluj-Napoca (Romania)

Diego Gonzalez-Aguilera

Ph.D. Dep. Cartographic and Land Engineering, University of Salamanca, Avilla, Spain

Dr. Francesco Tornabene

Ph.D. in Structural Mechanics, University of Bologna Professor Department of Civil, Chemical, Environmental and Materials Engineering University of Bologna, Italy

Dr. Maria Daniela

Ph.D in Aerospace Science and Technologies Second University of Naples, Research Fellow University of Naples Federico II, Italy

Dr. Omid Gohardani

Ph.D. Senior Aerospace/Mechanical/ Aeronautical, Engineering professional M.Sc. Mechanical Engineering, M.Sc. Aeronautical Engineering B.Sc. Vehicle Engineering Orange County, California, US

Dr. Paolo Veronesi

Ph.D., Materials Engineering, Institute of Electronics, Italy President of the master Degree in Materials Engineering Dept. of Engineering, Italy

Contents of the Issue

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Utilization of the Three-Dimensional Model to a Construction Production System

By Keizo Kanzaki

Abstract- The quitting a job of the expert worker and the lack of the technical transmission to the young worker with low birthrate, and the deterioration of the infrastructure institution which will increase rapidly in future will be the problem that must put up measures immediately in the construction business. CIM and i-Construction proposed by Ministry of Land, Infrastructure, Transport and Tourism enforce the improvement of the productivity of the construction site and the maintenance and check for the life cycle of the structure using three-dimensional model in order to solve such a problem, and they may be said that it is the big change of the construction production system. In this report, I survey three examples of the tool which I can utilize three-dimensional model for plan, measuring, construction, and maintenance based on a policy of CIM and i-Construction, explain an effective making method of the three-dimensional model suitable for a construction scale and contents and examine the effective utilization method and introduction effect in the construction production system.

Keywords: CIM, information-oriented construction, laser scanner device, UAV.

GJRE-E Classification: FOR Code: 290804

UTILIZATIONOFTHETHREEDIMENSIONALMODELTOACONSTRUCTIONPRODUCTIONSYSTEM

Strictly as per the compliance and regulations of:

Utilization of the Three-Dimensional Model to a Construction Production System

建設生産システムへの３次元モデルの活用 計画・施工・維持管理への活用事例

Keizo Kanzaki

Abstract- The quitting a job of the expert worker and the lack of the technical transmission to the young worker with low birthrate, and the deterioration of the infrastructure institution which will increase rapidly in future will be the problem that must put up measures immediately in the construction business. CIM and i-Construction proposed by Ministry of Land, Infrastructure, Transport and Tourism enforce the improvement of the productivity of the construction site and the maintenance and check for the life cycle of the structure using three-dimensional model in order to solve such a problem, and they may be said that it is the big change of the construction production system. In this report, I survey three examples of the tool which I can utilize three-dimensional model for plan, measuring, construction, and maintenance based on a policy of CIM and i-Construction, explain an effective making method of the three-dimensional model suitable for a construction scale and contents and examine the effective utilization method and introduction effect in the construction production system.

Keywords: CIM, information-oriented construction, laser scanner device, UAV.

I. はじめに

CIM や i-Construction の導入により，現場において３次元 モデルを活用する事例が増えつつある．CIM は，限られ た公共投資の中で効率的な社会資本整備を行うことや， ストック型社会への転換に向けた社会資本のアセットマ ネジメントの導入，地球環境に配慮した社会資本整備（アセスメント，LCA，リサイクル等）の実現などを目 的としており，近年では，単なるモデル化だけでなく， トータルマネジメントや社会資本整備の全体最適化とし て捉えられてきている１).

CIM は，建設構造物に各種の情報を付加したモデルを作成し，社会資本の整備や維持管理の効率化を目指す取り組みであるが，CIM 実現のためには，業務フロー，執行体制の見直しと，これを実現するためのデータ作成， 可視化，データ蓄積技術の確立が不可欠となっている． 特に構造物のモデル化については，「形状の見える化」だけでなく，地形・地質のモデル化も重要である．また， 構造物のライフサイクルにわたる維持管理・点検については， 「履歴の見える化」も重要な要素である．

現状での CIM の導入については，建設から維持管理・ 構造物の廃棄まで一貫して活用する将来の理想系をイメ ージしつつ，現時点の導入にあたっては「できることか ら実施していく」考えで段階的に進めていくことが現実 的な対応である２).

II. ３次元モデルの作成や活用に関する既往の研究

近年の測量技術は，３次元レーザスキャナ計測に代表 される面的な点群データ計測技術の普及により，従来使 用されてきた点と線で地形や構造物を表現していた時代 から，面で取得する方向へ，また，２次元から３次元でデ ータを取得する方向に移行してきている．

面で取得する手法は，広域な範囲を均一な成果で，安 価に取得できるという利点がある一方，点と線で取得す る方法は，電子基準点のみを使用した GNSS 測量も進め られており，基本的にはごく限られた範囲を密に高精度 で取得するという特質がある．

現況地形や既存構造物の ３ 次元点群データ計測手法を， 表-1 に列挙する．事業規模や目的に見合う精度を求めて， 最適な作成手法を選択する．専用の ３ 次元モデルで作成する構築する構造物の ３ 次元モデルと，表-1 の手法で作成する現況地形や既存構造物の ３ 次元モデルを合成する．

３次元モデルの作成手法である３次元レーザスキャナや 空撮測量（UAV）の研究としては，櫻井 3)らは，地上設置型レーザスキャナを用いて，傾斜面や整地されていな い地表面，欠損した地表面に対し，土工事の出来高管理

Author: Project Technology Department, Kumagaigumi Co, Ltd.
e-mail: kkanzaki@ku.kumagaigumi.co.jp

表 1: 3 次元点群データ計測手法の比較

手法	3 次元レーザスキャナ	空撮測量
内容	レーザ光線を発して，物体に少しづつ角度をずらして面的に照射しながら反射光を計測することにより，その範囲にある物体表面の点群データを作成	UAV（Unmanned Aerial Vehicle：無人航空機）を用いて，デジタルカメラと写真測量技術のソフトウェアで 3 次元点群データを作成
性能	①固定式地上レーザ計測（精度:数mm程度） ②MMS（精度：10cm程度） ③航空レーザ測量（精度:数10cm 程度）	UAV の普及により，比較的容易に広範囲を短時間で測量することが可能，精度はレーザスキャナに比べて低い

出典：「CIM 入門―建設生産システムの変革―」矢吹信喜著

のための地表面の生成が可能であることを実証実験で示した．また，田中 4)らは，レーザスキャナ搭載 UAV による点群データの解析・処理技術の調査を行い，今後の利活用へ向けた検証を行っている．櫻井 5)らは，UAV による空中写真測量時に作業者が考慮すべき項目を明らかにするために，空中写真測量における誤差要因の影響度や発生条件を調査し，各手法による点群データから 3 次元モデルを作成するにあたっての課題の抽出や実証結果を示している．今村 6)らは，MMS（Mobile Mapping System） を用いて道路施設（信号機灯具や白線）を対象に 3 次元点群データを用いた抽出方法について検証を行っている．

次に，3 次元モデルの公共工事への適用に関する研究としては，城古 7)らは，3 次元情報技術に関する活用事例をもとに，どのようなフェーズで，どのような効果，課題，変革があるかを抽出し，公共工事への適用を考察し， 公共土木工事が目指すべき方向性について述べている． また，宮武 8) 9) 10)らは，築堤事業の施工段階に CIM を適用した試行工事に関し，協議資料から設計照査，施工計画， 測量，施工･設計変更，検査までの各段階において，3 次元モデルを活用した結果について記述し，導入する場合の第三者の位置づけや役割，運用上の課題について述べている．藤田 11) らは，河川事業において CIM を導入し， 河川の 3 次元モデルによる不可視部分の可視化や経年変化の可視化，縦横断変化の可視化や過去の遍歴の投影が可能でありことを示し，これらが維持管理を行う上で有用であると述べている．

構造物に関しては，藤澤 12) らは，鉄道高架橋を対象として 3 次元モデルを作成して数量算出を行い，2 次元図面 から作成した数量の比較や，積算への適用を検証してい る．小林 13) らは，鋼上部工を対象に，作成する部材が非常に多い構造物の 3 次元モデルを効率的に構築する手法 を提案し，2 次元設計に対して業務効率化へ寄与する効 果を検証している．田中 14)，清水 15)，山岡 16) らは橋梁の維持管理段階で効率的かつ利用しやすい 3 次元モデルの 作成方法を提案している．

ダムやトンネル工事にあたっては，施工箇所の地質状 況を詳細に把握し，その状況に応じて最適な設計および 施工を実施することが重要であり，宇津木 17)らは，地質 の情報を 3 次元化する CIM 対応ソフトを開発し，施工に 活用し，維持管理に必要な属性情報を選定している．ま た，杉浦 18)らは，施工 CIM として切羽情報や覆工情報を 3 次元モデルに取込み，一元管理を行い，維持管理 CIM へ の展開について検証している．畑 19)らは，山岳トンネル において，切羽前方地質情報を CIM に連携して，予測型 CIM を開発し，トンネル周辺の地質情報を明確化し，地 質構造モデルを作成することで施工後の維持管理情報と して活用している．

これらの先行研究は，3 次元モデルの作成手法を精度や効率化の面から検証し，3 次元モデルを公共工事の各施工段階で運用した結果や，維持管理情報としての利活用の現状把握や今後の可能性について記述されており， 非常に有益なものである．ただ，3 次元モデルの作成手法を選択した経緯について言及したものは少ない．CIM や i-Construction の概念は，計画・調査から検査，維持管 理まで 3 次元モデルを主体として実施することであるが， 事業内容，規模，工種により最適な 3 次元モデルの作成手法があり，かつどの建設生産プロセスにおいて 3 次元モデルが有効に活用できるかは事業内容，工種によって異なることが考えられる．

本稿は，工種の異なる 3 事例を紹介し，計画段階から 測量，施工管理，維持管理に至る建設生産プロセスに着 目し，3 次元モデルの作成手法を選択した

Global Journal of Researches in Engineering (E) Volume XX Issue II Version I Year 2020

経緯，および 建設生産プロセスにおける有効な活用方法，その導入効 果について検証する．

III. 建設生産システムへの適用事例

本章では，建設生産システムを①計画，②測量･施工，③維持管理への利用に分類した上で，3 次元モデルを活 用している 3 事業（橋梁下部工工事，大規模土工事，山 岳トンネル工事）について報告する．

a) 計画段階への適用事例 ～橋脚下部工工事～

i. 事業内容及び 3 次元モデル作成手法

筆者らは，中部地方整備局発注の高速道路で橋脚下部 工を 3 基（1 基はフーチングのみ）施工する工事を，CIM 試行工事として取組んでいる．写真-1 に示す工事箇所の中央分離帯付近に橋脚を構築する．計画段階で構築する 構造物と既存の防音壁や地下構造物との離隔を把握する ことが施工前に要求されたため，3 次元にモデル化する ことが視覚的に効果的であると考えた．3 次元モデル作 成手法として，現況測量するにあたり，施工箇所が幹線 道路であるため，UAV 測量を行うには許可を申請する 必要がある．また，道路周囲の防音壁や中央分離帯の突 起部などを高い精度でモデル化する必要があったため， 固定式 3 次元レーザスキャナ（GLS-2000：TOPCON 製） で測量を実施することとした．測量期間は，測量範囲（縦断 150m，横断 40m）において，3 日間（機器据付け 回数約 30 回）の日数を要した．3 次元点群データ（図- 1）取得後，3 次元モデルを作成し，さらに 2 次元図面か ら専用の 3 次元ソフトで作成した 3 次元の構造物モデルや 地層データを合成した（図-2.

次に，鉄筋の組立工に関しては，鉄筋梁部は過密鉄筋 で，PC 鋼材も配置することから鉄筋と PC 鋼材が輻輳す ることが想定された．このため，事前に 2 次元図面から 鉄筋の 3 次元モデル化を行い，組立てる上で支障となる 箇所を把握することとした（図-3，図-4）．

写真-1 工事箇所施工前状況

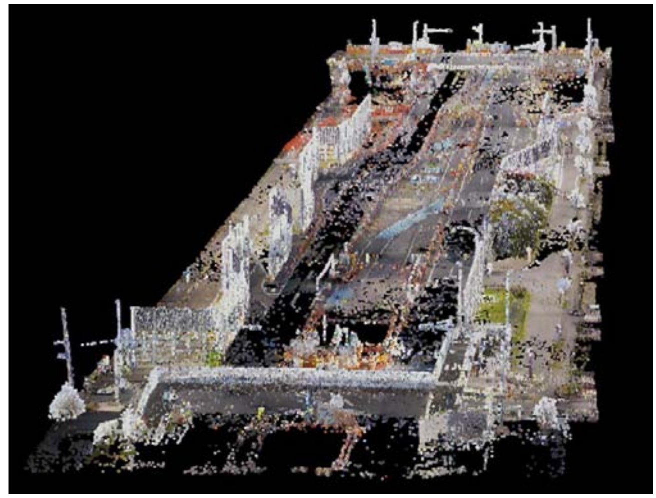

図-1 3 次元点群データ

ii. 導入による効果

計画段階で 3 次元レーザスキャナによる測量を実施し， 現況地形と既存構造物の 3 次元モデルの作成と，構築する橋脚の 3 次元モデルを合成すること，既存構造物と橋脚の位置関係が正確に把握でき，防音壁との離隔が施 工に支障とならないか 3 次元的に確認することが可能となった．鉄筋についても，3 次元化することにより，パーツ毎の 2 次元図面では把握できなかった鉄筋の干渉部を簡単に抽出することが可能となった．また，事前に鉄筋輻輳部の組立て完了後の 3 次元モデルを見ることで， 鉄筋組立て手順のイメージをたて易くなり，組立て前に， 組立て手順を職員と鉄筋工で確認でき，施工時に組立て不可能になるなどの手戻りを防止することができた．

以上より，本工事では計画段階におけるレーザスキャ ナによる 3 次元モデル化が「形状の見える化」に効果を 発揮し､施工にあたって非常に役立ったといえる．

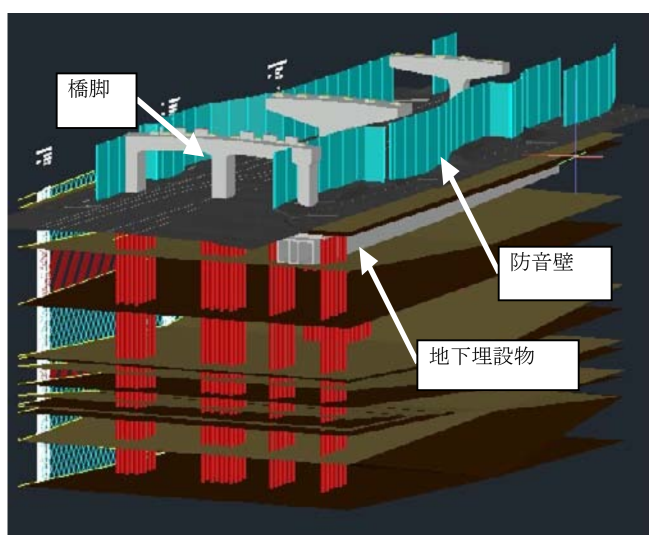

図-2 3 次元モデル

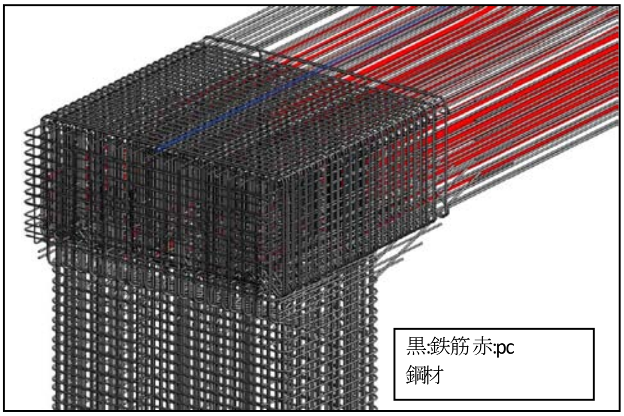

図-3 鉄筋・pc 鋼材の 3 次元化

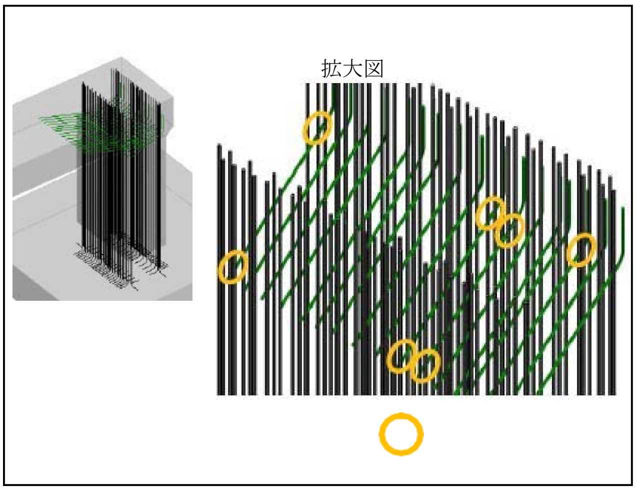

図-4　干渉鉄筋部

b)　測量・施工段階への適用事例 ～大規模土工事～

i.　事業内容及び 3 次元モデル作成手法

静岡県発注の工業団地の造成工事で，施工面積約 31ha，　切土量約 76 万 m3，盛土量約 63 万 m3 の大規模土工事である．本工事では，i-Construction を見据えて施工当初から 3 次元 モデルを作成し，測量や施工段階で情報化施工の運用や 進捗管理を実施している（図-5）．

3 次元モデル作成手法として，広大な施工面積の測量 を短期間で行う必要があること，数十万 m3 の土量算出 のため，精度は数 cm 単位で良いこと，などの理由から UAV を使用した（写真-2，表-2）．UAV に搭載したデジ タルカメラで航空写真を撮影し，専用のソフトで点群デ ータを作成した（写真-3，図-6）．UAV による測量方法 は，現況測量として，施工範囲を伐採が完了した箇所か ら 3 回に分けて順次実施した．さらに，設計図面より最 終仕上がり形状をを 3 次元モデル化し（図-7），UAV 測 量による 3 次元地形データと比較して施工段階での土量 等高線分布図を作成した（図-8）．切土･盛土量を算出 できるとともに，運土計画を立てることができた．

さらに，施工時の進捗管理を目的として，土工事の竣 工（平成 29 年 12 月）に合わせて 2 回(進捗 40%時点と進捗 70%時点)，UAV 測量を実施し，土工量を把握した．

施工は，UAV 測量で得られた現況地形の 3 次元データ と 2 次元設計図書から作成した最終仕上がり形状の 3 次元 設計データを利用する．

盛土材の敷均し作業は，ブルドーザに高精度の GNSS 受信機を設置し，これらの 3 次元データをブルドーザに取込むことで，機体位置の標高と設計高さをリアルタイムに照合できる．予め取込んだ 3 次元データをリアルタイムに照合して，機体位置の標高と設計高さを把握する． 自動制御機能により排土板を施工箇所位置の設計撒き出し高さに自動で上下させ，撒き出し，および敷均しを行う．オペレータは，運転席のモニターで設計値と排土板の高さを確認しながら前後進を繰り返す．排土板は指定通りの高さまで自動で可動する（写真-4，写真-5）．

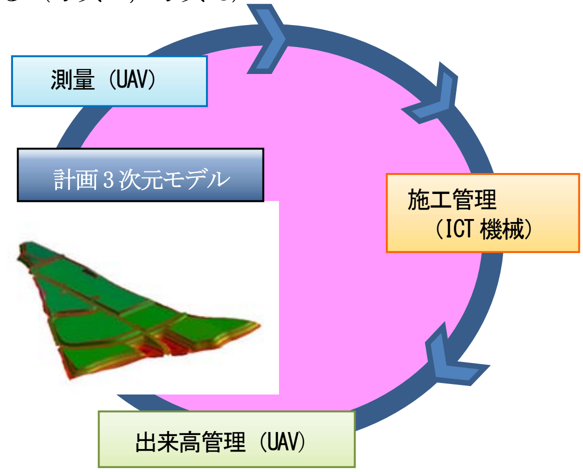

図-5 取組み概念図

写真-2 UAV（SPIDER CS6）

表-2 UAV 仕様（SPIDER CS6）

項　　目	仕　　様
機体重量	3,800 g
外形寸法	1,000×1,000×400mm
躯　　動	モータ躯動
耐　　風	15m/s 以下
飛行時間	10 分～25 分
撮影範囲	約 1,000m
到達高度	250m

写真-3 航空写真

図-6 点群データ

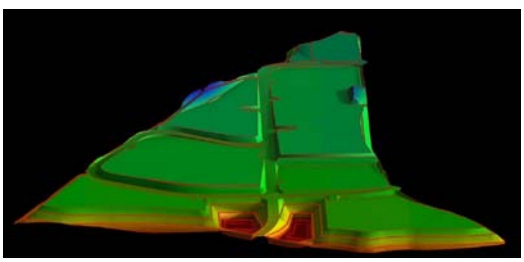

図-7 最終仕上がり形状（3次元モデル）

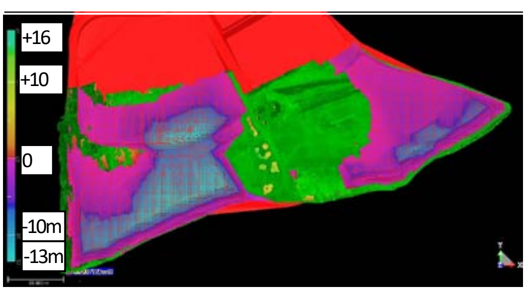

図-8 土工等高線分布図

さらに，ブルドーザに無線機（携帯データ通信：Wi- Fi）を搭載し，サーバーとのネットワークを構築するこ とで情報の送受信を可能にして重機の位置情報を把握で きるシステム（システム名:VisionLink）を導入した．本 システムにより，パソコン上で日々の重機や出来形の情 報をリアルタイムに確認でき，施工管理の「見える化」 に役立っている．

モニター画面の一例を示す．ブルドーザが作業してい る位置の標高を色分けで表示する．画面上で任意の断面を設定して表示でき，計画に対して現在どのあたりで作業を行っているか進捗状況を把握できる（図-9）．また， ブルドーザが作業した範囲における概算の土量を計算し， 切土量・盛土量の算出を行う（図-10）．

写真-4 排土板制御システム搭載ブルドーザ

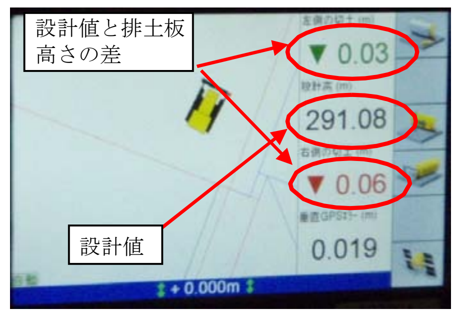

写真-5　モニター画面

図-9 ブルドーザが作業している標高表示

図-10 概算切盛土量表示

敷均し後の締固め作業は，振動ローラを使用する．機 体の屋根に設置した GNSS 受信機で位置を把握し，締固め面の施工情報（締固め範囲，高さ）に加え，締固め位 置，締固め回数を運転席のモニター画面にリアルタイム に表示する．

オペレータは機体を操作しながらモニター上のメッシュ（50m×50m）の色が転圧する毎に変わっていくのを確認し，所定の回数（試験施工で決定した必要な回数）の色になるのを確認して終了とする（写真-6，写真-7）．

法面掘削作業は，バックホウを使用する．機体には高 精度の GNSS 受信機を設置し，アーム部に取付けたチルトセンサーより，バックホウとバケットの位置を測定す るガイダンス機能により作業を行う．オペレータのモニ ター画面には，最終形状の 3 次元設計データから得られ る施工箇所の設計切土ラインとバケットの位置が表示さ れる．オペレータはバケットの位置と設計ラインまでの 距離をモニターで確認しながら作業することができる（写真-8，写真-9）．

さらに，最終仕上げ時はマシンコントロール機能を使用して法面整形を実施している．バケット角度保持モード機能を搭載しているため，バケットの角度が固定され， オペレータは上下に操作するだけで，設計切土ラインに整形できるという仕組みになっている（図-11.

写真-6 転圧管理システム搭載振動ローラ

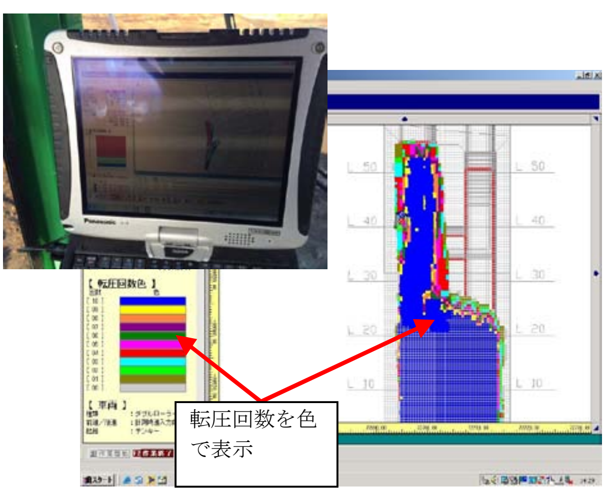

写真-7 モニター画面

写真-8 マシンガイダンスバックホウ

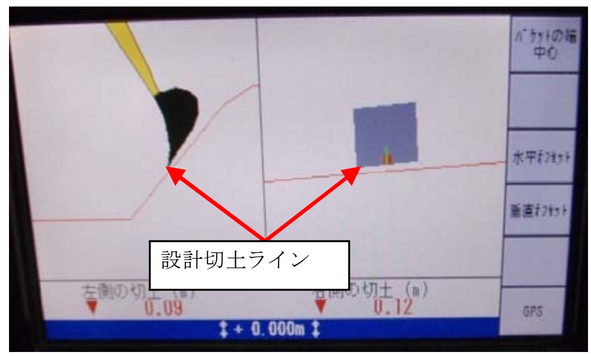

写真-9 モニター画面

出典：HITACHI カタログ
「ICT 油圧ショベル ZAXIS200」

図-11 マシンコントロール機能概念図

c) 導入による効果

測量に関しては，UAV を使用することにより，航空写真から点群データ，3 次元モデル作成に費やす時間は 約 1〜2 週間である．本工事のような大規模な施工面積の 場合，従来は測量だけで 2 週間以上かかるため，測量か ら 3 次元モデル作成に費やす時間を大幅に削減すること が可能となった．また，施工段階においては，切土量， 盛土量が自動算出できるため，設計数量との対比や運土 計画，出来高管理を効率的に行うことができた．

GNSS を用いた ICT 機械の導入により，基本的に測 量杭は不用となるため，丁張り設置や検測作業がなくな り測量作業の省力化を図ることができた．また，施工時 も丁張りを目安にした点や線の管理に代わり，モニタ画 面で施工範囲全面の面的な管理を行え，仕上がり精度の 向上や締固め回数の正確な管理を行うことが可能となっ た．熟練でない経験の浅いオペレータが作業しても，熟 練労働者と同等の仕上がりを行うことが可能となる．

締固め作業における施工情報は，自動で保存され，盛 土の品質データとして自動保存できる．

以上より，このような施工面積の広い造成工事では，測量で UAV を，施工管理で ICT 機械を使用することで，施工の効率化，省人化，品質の向上に非常に役立つとい える．

IV. 維持管理への利用事例 ～山岳トンネル工事～

a) 実施内容及び 3 次元モデル作成手法

近畿地方整備局発注の山岳トンネル（延長 1,295m） 工事である．工事完了後の維持管理段階への利用を主目 的とするため，表-1 による作成手法は選択せず，専用ソ フトで CIM 用 3 次元モデルを作成した．作業は，3 次元モ デルに施工データ（品質・出来形）を入力することに重 点をおき，かつ地質脆弱部の地質モデルも 3 次元化し， これらを維持管理データとして竣工時に発注者へ引渡し を行った．

掘削時は，切羽写真を 3 次元モデルに連続的に並べ切 羽観察情報を入力した（図-12）．覆工も 3 次元モデル化し，コンクリート品質データや出来形情報を入力し，覆 工ブロックをクリックするとクリックしたブロックの属 性情報が全て見れるようになっている（図-13）．

3 次元地質モデル作成手法として，①地質縦断図，② 地質平面図，③トンネル線形図，④標準断面図，⑤先進 調査ボーリング（2 箇所），⑥切羽写真を参考資料として，専用の 3 次元地質モデルソフトを用いて，大局的な地質モデルを作成した．本トンネルは，古第三紀の凝灰 角礫岩(Ytb)が全域にわたり分布し，その上に古第三紀の砂岩(Yss)，段丘堆積物(tr)，崖錐堆積物(dt)が累重する．これらの地層のモデリングを実施した（図-14,図- 15）．

先進調査ボーリング結果では，地質脆弱部，破砕帯部 ともボーリング間のほぼ全体に角礫状・砂礫混じり粘土 状が分布しており，切羽写真データでも亀裂が発達して いることが確認できた．これらと，地質縦断図や地表面 形状から，地質脆弱部，破砕帯部の境界面を想定したの ち地質モデルを推定した．走向方向は，地形データから 低土被りとなっている沢筋を通るように分布させた（図-16,図-17）．

さらに，脆弱部（Ytb 層風化部）と破砕帯部を全体の 3 次元モデルにはめ込んだものを図-18 に示す．このモデルから縦断切断面を作成することにより，将来，計画 されている II 期線トンネル部の地質状況を推定すること ができ， II 期線施工の掘削時に役立てることができる（図-19）．

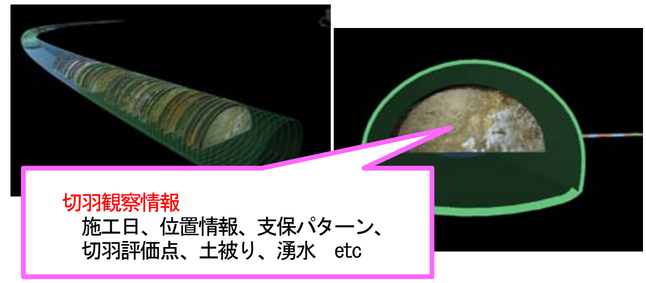

図-12 切羽モデル図

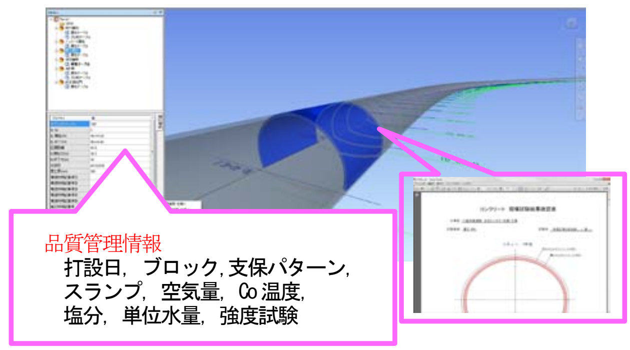

図-13 覆工モデル図

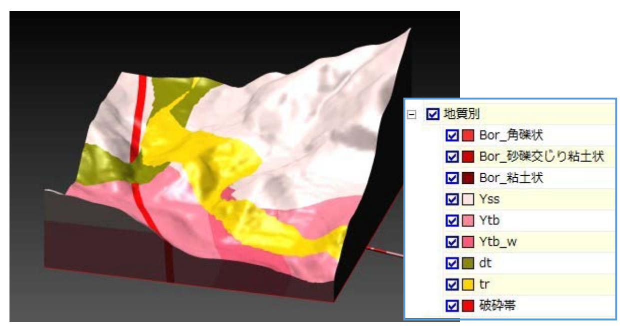

図-14 地質モデル全体図

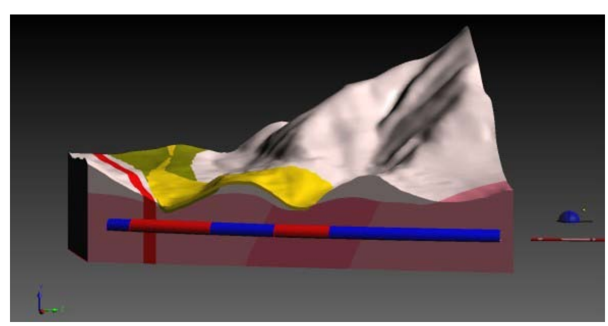

図-15 地質モデル切断図

Global Journal of Researches in Engineering (E) Volume XX Issue II Version I Year 2020

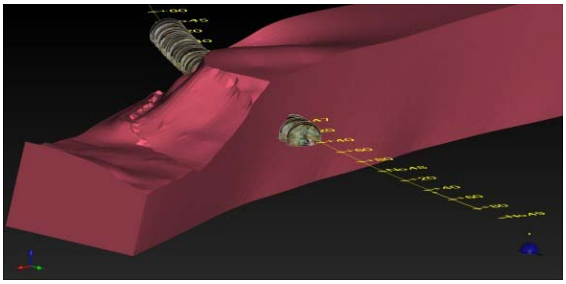

図-16 脆弱部 3 次元モデル化

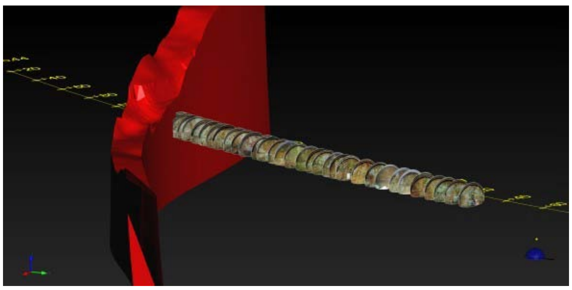

図-17 破砕帯 3 次元モデル化

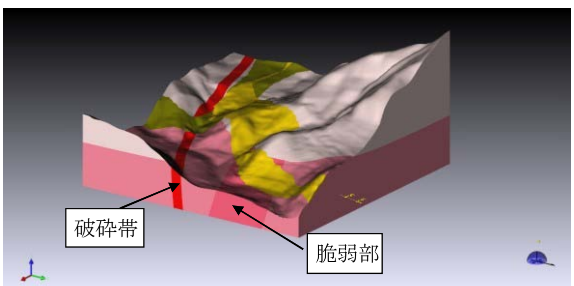

図-18 全体地質モデル化（脆弱部･破砕帯）

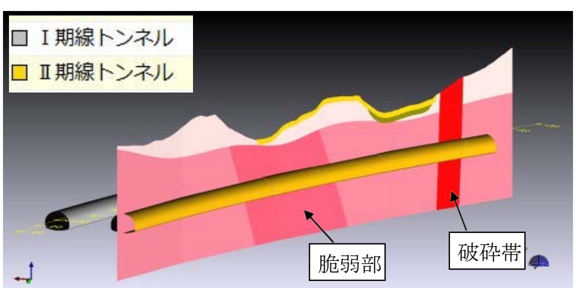

図-19 Ⅱ期線トンネル CL での縦断切断図

b) 導入による効果

今回，維持管理業務への利活用ということで，トンネル施工時のデータを 3 次元モデルに取り込むことを主業務とし，さらに，各種地質データを基に地質モデルを 3 次元化し，地質脆弱部や破砕帯区間の可視化を可能とした．これらのデータをしゅん工時に発注者に引き渡し，将来，維持管理・点検時にこの 3 次元モデルに点検結果を順次保存していくことで，「履歴の見える化」を行うことが可能となった．

また，3 次元トンネル CIM データ（掘削時の情報，計測データなど）に地質モデルを重ね合わせたことで，トンネル施工情報と地質情報（地質脆弱部や破砕帯区間）が関連付くとともに，Ⅱ期線施工時の非常に有効なデータとして利用することが可能となる．

V. おわりに

工種の異なる 3 事業に対し，施工規模や施工内容に適した 3 次元モデルの作成手法，建設生産プロセスにおける活用方法や導入効果について検討を行った．

3 次元点群データの作成手法は，主に 2 つの手法があるが，施工範囲が大きくなく，既存の道路施設構造物など高い精度を要求される 3 次元モデルの作成には，3 次元レーザスキャナを使用することで，施工前に既存構造物と構築構造物の位置関係を詳細に把握でき，計画段階での形状の見える化」に効果を発揮した．

一方，施工面積が広い造成工事において，施工前の土工量把握や施工段階での進捗管理を行うには，UAV を使用することで，従来の方法より短時間で土工量を算出できた．さらに，3 次元データを基にした ICT 機械の稼働により，施工の効率化と品質向上に効果を発揮した．

山岳トンネル工事においては，トンネル線形の 3 次元モデルに切羽情報や覆工データを属性情報として入力することで，「履歴の見える化」が可能となり，今後の維持管理業務に活用できる．さらに脆弱化した地質部の 3 次元データを重ね合わせることで，次期工事の施工情報として有益なものになると考えられる．

謝辞：CIM や i-Construction の導入にあたり，ご指導を賜った各発注者の皆様にこの場を借りてお礼を申し上げます．

参考文献

1. 佐藤直良，矢吹信喜：CIM の歴史と可能性，土木学会誌 Vol.100 No.6，pp.10-13，2015
2. （一財）日本建設情報総合センター：CIM 技術検討会平成 25 年度報告書，pp.12-65，2013.
3. 櫻井淳，田中成典，中村健二，窪田諭，中原匡哉，平謙二：レーザスキャナを用いた施工現場の常時観測における地表面生成技術の開発，土木学会論文集 F3（土木情報学）,Vol.72,No.2，Ⅰ_219- Ⅰ_230,2016
4. 田中成典，窪田諭，今井龍一，中村健二，山本雄平， 寺口敏生，櫻井淳：レーザスキャナ搭載 UAV 開発のための点群データ計測の利用場面と解析・処理技術に関する調査研究，土木学会論文集 F3（土木情報学）,Vol.72,No.2, Ⅱ_82- Ⅱ_89,2016
5. 櫻井淳，田中成典，中村健二，窪田諭，今井龍一， 重高浩一：UAV の空中写真測量による施工管理のための計測手法の提案，土木学会論文集 F3（土木情報学）,Vol.72,No.2, Ⅱ_73- Ⅱ_81,2016

6. 今村一紀，佐田達典，江守央：MMS による 3 次元点群データを用いた道路構造物抽出に関する研究，土木学会論文集 F3（土木情報学）,Vol.71,No.2, Ⅰ_106- Ⅰ_113,2015
7. 城古雅典，森脇明夫，有賀貴志，石川和弘，福士直子：公共土木工事への 3 次元情報技術の適用に対する提案， 土木学会論文集 F4 （ 建設マネジメント）， Vol.72, No.4, Ⅰ_135- Ⅰ_144,2016.
8. 宮武一郎，田村利晶，盛伸行，岡井春樹，高岸智紘： CIM を適用した築堤事業の施工段階における 3 次元モデルの作成・修正の支援に関する一考察，土木学会論文集 F4（建設マネジメント）,Vol.72,No.4, Ⅰ_145- Ⅰ_154,2016
9. 宮武一郎，岡崎仁司，塚原大輔，栗山卓也，松田寛志：3 次元モデルを利活用する堤防設計に関する一考察，土 木学会論文集 F3（土木情報学）,Vol.72,No.2, Ⅰ_42- Ⅰ_51,2016
10. 宮武一郎，田村利晶，盛伸行，岡井春樹，高岸智紘：築堤事業の施工における CIM の適用についての一考察，土木学会論文集 F3（土木情報学）,Vol.71,No.2, Ⅱ_18- Ⅱ_27,2015
11. 藤田陽一，星野裕司，小林一郎，水野純生：複数の 既存データを併用した河川管理 CIM モデルの一考察， 土木学会論文集 F3（ 土木情報学）,Vol.71,No.2, Ⅰ_79- Ⅰ_86,2015
12. 藤澤泰雄，矢吹信喜，五十嵐善一，吉野博之：鉄道高架橋を対象とした三次元設計モデルの積算・施工への利用，土木学会論文集 F3（土木情報学）,Vol.67, No.2, Ⅰ_8- Ⅰ_17,2011
13. 小林優一，吉野博之，谷口和昭，金光都，徳武広太郎：CIM の概念を用いた鋼上部工の 3 次元モデルの構築に関する効率化の一提案，土木学会論文集 F3（土木情報学）,Vol.72,No.2, Ⅱ_90- Ⅱ_95,2016
14. 田中成典，北川悦司，姜文渊，安彦智史，川野浩平：道路橋上部工の維持管理のための 3 次元現況図の自動生成に関する研究，土木学会論文集 F3（土木情報学）,Vol.68,No.2, Ⅰ_181- Ⅰ_189,2012
15. 清水智弘，吉川眞，瀧浪秀元，御崎哲一，髙橋康将， 中山忠雅，内田修，近藤健一：3D モデルを用いた橋梁維持管理システムの開発， 土木学会論文集 F3（土木情報学）,Vol.69,No.2, Ⅰ_45- Ⅰ_53,2013
16. 山岡大亮，青山憲明，谷口寿俊，藤田玲，重高浩一：維持管理での利用を想定した橋梁の 3 次元データモデル標準の策定，土木学会論文集 F3（土木情報学）,Vol.71,No.2, Ⅰ_204- Ⅰ_211,2015
17. 宇津木慎司，中谷匡志，佐々木照夫：地質情報 CIM 管理システムの構築および施工現場への適用，土木学会論文集 F3（土木情報学）,Vol.72,No.1,24-31,2016.
18. 杉浦伸哉，後藤直美：紀勢線見草トンネル工事における施工 CIM から維持管理 CIM への取組み，土木学会論文集 F4（建設マネジメント）,Vol.71,No.4, Ⅰ_227- Ⅰ_233,2015
19. 畑浩二，杉浦伸哉，後藤直美，藤岡大輔：山岳トンネルにおける ICT を活用した予測型 CIM の開発，土木学会論文集 F3（土木情報学）, Vol.71, No.2, Ⅱ_78- Ⅱ_85,2015.

This page is intentionally left blank

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Qualitative Analysis of Sustainable Indicators: An Approach to Correlate Sustainable Indicators with Transportation Practices

By Hariharan Naganathan, Aaron D Sauer, Oswald Chong & Jonghoon Kim

Missouri State University

Abstract- Transportation sustainability is centered on being the linchpin to cultivate innovations and enhance safer environmental standards. The public and private agencies adopt sustainable practices integrating their policies in order to elevate sustainability performances. There is an advent need of developing a tool for quantifying the transportation policies and practices. This paper explains (1) the fundamental practices adopted by different transportation agencies; (2) the impacts of three pillars on developing the sustainable indicators; (3) the selection of indicators and their grouping; and (4) the statistical relationship between indicators with the real-time variables population and GDP. This performance benchmark aims to quantify the sustainability practices of the state and its transportation agencies by assessing their environmental, social, and economic practices. The paper examines the relationship between the selected sustainable indicators and establishes the framework for the sustainability of transportation. This framework is a starting point for adding more relevant indicators to measure the sustainability of transportation when data become available.

Keywords: sustainable transportation, transportation policies, performances, statistical analysis, correlation, the impact of indicators.

GJRE-E Classification: *FOR Code: 290899*

QUALITATIVEANALYSISOFSUSTAINABLEINDICATORSANAPPROACHTOCORRELATESUSTAINABLEINDICATORSWITHTRANSPORTATIONPRACTICES

Strictly as per the compliance and regulations of:

Qualitative Analysis of Sustainable Indicators: An Approach to Correlate Sustainable Indicators with Transportation Practices

Hariharan Naganathan [α], Aaron D Sauer [σ], Oswald Chong [ρ] & Jonghoon Kim [ω]

Abstract- Transportation sustainability is centered on being the linchpin to cultivate innovations and enhance safer environmental standards. The public and private agencies adopt sustainable practices integrating their policies in order to elevate sustainability performances. There is an advent need of developing a tool for quantifying the transportation policies and practices. This paper explains (1) the fundamental practices adopted by different transportation agencies; (2) the impacts of three pillars on developing the sustainable indicators; (3) the selection of indicators and their grouping; and (4) the statistical relationship between indicators with the real-time variables population and GDP. This performance benchmark aims to quantify the sustainability practices of the state and its transportation agencies by assessing their environmental, social, and economic practices. The paper examines the relationship between the selected sustainable indicators and establishes the framework for the sustainability of transportation. This framework is a starting point for adding more relevant indicators to measure the sustainability of transportation when data become available.

Keywords: sustainable transportation, transportation policies, performances, statistical analysis, correlation, the impact of indicators.

I. Introduction

The transportation sector is the bloodline of the U.S economy, and the sustainability of this sector has an enormous impact on its growth. Alternatives for nonrenewable resources are looked upon by the researchers to enhance transportation sustainability. Transportation influences all aspects of the economy, environment, and society and generates long-term impacts on humanity (Dearing, 2000). Sustainability in transportation addresses the basic needs of societies such as safety and is in a manner consistent with the health of humans and the ecosystem through transportation infrastructure (CH2M HILL, 2009). The active structure of transportation planning and management relies entirely on sustainability. Federal and state transportation agencies perform a pivotal role in implementing sustainability in the transportation sector. The ever increasing demand for nonrenewable resources has forced decision-makers of the transportation sector to look for alternatives that can satisfy or improve our living environment, economy, and society. The purpose of incorporating sustainability into the transportation sector is to alleviate the environmental and social impacts caused by the sector while sustaining its contributions to the economy. A knowledge platform integrates different policies, practices, and technologies in order to reflect sustainability in different situations and conditions (Andrea, 2013). These knowledge platforms of these sustainable practices adopted by different transportation agencies are not promulgated wisely (Daniel, 2011). The Departments of Transportation (DOTs) do not clearly understand the relationships between sustainable practices and their ability to create jobs, reduce carbon emissions and pollution, and provide social benefits to their residents. Also, many of these sustainability initiatives implemented by the states are not appropriately quantified. Thus, the level of sustainability adopted by different state agencies cannot be quantified and measured. These policies and practices can be quantified using sustainable indicators, which is selected with the available data from reliable sources.

The Transportation Demand Management (TDM) program is used to develop strategies and policies that help in reducing the traffic loads and other transportation-related issues (U.S DOT, 2008). It is adopted by various state transportation agencies but not utilized at the fullest. Some of the agencies incorporated this program later dropped it due to its strategies and policies that can be adopted only at local levels and often at the project level (Alameda County Transportation comission, 2009). The need for demand management is critically high since oil prices, and publicly owned vehicles are increasing rapidly (U.S DOT, 2008). The transportation research board stated that some of the factors influencing sustainability in transportation include nonrenewable fuel depletion, global climatic change, local air quality, fatalities and injuries, congestion, greenhouse gas emissions, and

Author α: Ph.D., Assistant Professor, Department of Construction Management, Wentworth Institute of Technology, Boston, Massachusetts. e-mail: naganathanh@wit.edu

Author σ: Ph.D., Assistant Professor, Department of Constriction Management, Missouri State University, Springfield, Missouri. e-mail: ASauer@missouristate.edu

Author ρ: Ph.D., Associate Professor, School of Sustainable Engineering and Built Environment, Arizona State University, Tempe, Arizona. e-mail: ochong@asu.edu

Author ω: Ph.D., Assistant Professor, University of North Florida, Construction Management Department, e-mail: jongkim@unf.edu

noise pollution (TRB, 2005). There are several other organizations like American Public Transportation Association (APTA), American Public Works Administration (APWA), Energy Information Administration (EIA), and Energy Protection Agency (EPA) that adopts different policies and strategies in order to achieve transportation sustainability. These organizations have quantified several sustainable indicators, which are derived from the policies and strategies they have adopted. Most of these indicators are quantified through regular data collection, while other indicators have not yet been quantified.

II. Impacts of Three Pillars on Sustainability

Sustainability is sometimes defined narrowly. For example, some focus on resource depletion and air pollution problems, while others identify it as the most significant long-term ecological risk. These focuses are prone to be neglected by engineers, planners, and architects alike. The most common approach to tackle various sustainability issues is the triple bottom line approach. The triple bottom line approach relates between vibrant community (people), healthy environment (planet), and firm profitability (profit). According to Litman (2011), this approach to sustainability can be represented by a Venn diagram, which identifies the interrelationship between social, economic, and environmental issues.

III. Social Issues

Social variables refer to the social dimensions of community, society, or region and include education, equity, and access to social resources, health and well-being, quality of life, and social capital (Flaper, 2009). Social indicators measure the impacts of an action on the community. It includes population size, composition and growth, life expectancy, and literacy (UNSDa, 2012). Some of the factors, according to Flaper (2009), are unemployment rate, female labor force participation rate, median household income, relative poverty, percentage of the population with a post-secondary degree or certificate, average commute time, violent crimes per capita and health-adjusted life expectancy.

The U.S. Government Accountability Office (GAO) has developed a set of social indicators (called national key indicators) that measure the U.S. social impact performance. The indicators are divided into different stages and include factors like health, macroeconomics, education, crime, safety, social support, community, governance, sustainability, and transparency. These indicators also overlapped some economic indicators. Economic indicators are often intimately associated with social indicators as the economy is often closely tied to the welfare of the community and society (Riche, 2010).

IV. Economic Issues

Economic health is a critical component of any nation. A monetary system influences the wealth of the nation and its citizens. The economic variables include income, climatic factors, and expenditures (Riche, 2010). Regional and global economic and political instability threatens the supply of critical resources, and often create commodity price shocks (Gelos & Ustyugova, 2011). Right in between, the supply and demand of these resources lay in the transportation system that ties both together. Increases in the price of energy push up the cost of various commodities, which elevates the general prices (inflation). The responses towards prices of different commodities vary among different countries, as Gelos & Ustyugova (2011) suggested that drivers of the prices include market openness, trends of import and export, the share of food and transport on consumer price index, fuel use in a country, financial development, and the health of the labor market and financial institutions. Increase in gas prices reduce disposable income and affect economic growth as a result. The economic sustainability of transportation should focus on the efforts of transportation systems on various economic factors.

V. Environmental Issues

Environmental indicators measure the effects of human activity on the environment and ecosystems. There are national, regional, and local laws that target these environmental impacts. Example of these agencies includes the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Agency (NOAA). These regulations target to eliminate the environmental impact of product manufacturing and from various other economic activities. These agencies focus on enhancing the water and air quality, reducing energy use, eliminating radiation and toxicity, improving land quality, reversing climate change, controlling chemical use, etc. These indicators are often used to quantify the environmental impact of products, policies, and systems (UNSD, 2011).

Air pollution, noise, water pollution, depletion of nonrenewable resources, landscape degradation, heat island effects (increased ambient temperature resulting from the pavement), and ecological degradation (Litman, 2011) are some of the environmental impacts created by the transportation systems. Some of the other environmental impacts are caused by the high concentration of sulfur dioxide and nitrogen oxides, pollutants, and excessive nutrients, fossil fuel and electricity consumption, improper solid and hazardous waste management, and change in land use and land cover.

VI. Prior Research on Sustainable Transportation

Transportation influences all aspects of the economy, environment, and society and generates long-term impacts on humanity (Dearing, 2000). Sustainability in transportation addresses the basic needs of societies such as safety and is in a manner consistent with the health of humans and the ecosystem through transportation infrastructure (AASHTO, 2009). The Bruntland report published by the World Commission on environment and development defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Oswald, 2008). There is numerous research on sustainable transportation developed by different researchers, particularly on sustainable indicators and its development. Since sustainable development became an international priority in the 1980s and 1990s, infrastructure sustainability has become a growing area of interest in practice, research, and education (AdjoAmekudzi, 2005). Examples of researchers who did intense work on sustainable indicators of transportation include Litman (2011), Adjo (2005), Gudmundsson (2000), Meyers (2000), Cortese(2003), Wheeler(2003), etc.

According to AdjoAmekudzi (2005), the frameworks found in the literature can be placed into three categories which linkages-based, impact-based, and influence oriented (Adjo Amekudzi, 2005). Similarly, Litman (2011) includes various indicators based on the three pillars, which include economic, social, and environmental activities. This research moves a step forward from this level to prove the positive correlation between these indicators, which is considerably used by researchers for performance analysis of sustainable transportation.

VII. Sustainable Transportation Policies

Sustainable strategies and policies are adopted under the banner of sustainable initiatives by most cities (Goldman, 2006). The purpose of sustainable policies optimizes the environmental, economic, and social benefits of the transportation systems (OECD, 2000). Measurable outcomes are needed in order to determine the success of the actual sustainability policies.

The funding for public transportation has increased over the last two decades (D. Banister, 2007). Many innovations in transportation practice occurred and continue to take place in the transportation sector, and many of these innovations may serve the goal of a more sustainable transportation system (Goldman, 2006). The New York State Department of Transportation (NYSDOT) sustainable mission is to integrate sustainability into different transportation practices that include the planning, constructing and maintaining of the transportation system, and the optimizing of internal resources of DOT. (NYSDOT, 2013).

One of the most extensive sustainable frameworks is the performance planning process defined by the Government Performance and Results Act (GPRA). GPRA is adopted as a U.S. legislation in 1993 and with bi-partisan support. This framework, the GPRA, and the other "Sustainable Policy" framework will be the main focus in this section (Henrik Gudmundssun, 2001). Most of the transportation agencies align themselves with the framework and concepts of sustainable transportation that are more relevant to their states. Department of Transportation (DOTs), American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), Federal Transit Administration (FTA), United States Department of Transportation (USDOT) and various regional transportation agencies have initiated numerous sustainable transportation programs and initiatives that target the transportation sustainability of the states, counties, cities, and communities. It in turn elevated the standards of transportation through the integration of sustainable practices to a certain extent.

VIII. Sustainable Practices

USDOT encourages the state DOTs to initiate sustainable practices and implement measures to develop that green transportation. DOT has defined five strategic goal areas. There have not been changes between 1997 and the revised 2000 Strategic Plan. The five-goal areas cover Safety, Mobility, Economic Growth and Trade, Human and Natural Environment, and National Security (Henrik Gudmundssun, 2001). Many DOTs attempted to implement many sustainable practices based on the state population and the budget on their sustainable practices.

Examples of these sustainable practices include 1. Renewable energy: The California Department of Transportation (Caltrans) installation of a large number of wind turbines and the development of many renewable energy production facilities across the state of California (Caltrans, 2013), and the Texas Department of Transportation (TxDOT) initiative to develop and utilize of renewable and natural resources (mostly ethanol) as the alternative fuel in the state (TxDOT, 2013), and the Iowa Department of Transportation provides extensive supports for the development of ethanol (renewable energy) program in the state; 2, Green Transportation and Highway System: The New York State Department of Transportation (NYSDOT) developed the green and blue highways initiatives, which can provide green transportation throughout the state (NYSDOT, 2013), the Washington Department of Transportation (WSDOT) developed the standards for green highway design and initiated several green highway projects (e.g. the Electric Highways, Smarter Highways and Sustainable Transportation projects), the New Mexico Department of Transportation (NMDOT) and the Pennsylvania Department of Transportation (PENDOT) invests their growth through Smart transportation system for roadways (NMDOT, 2013).; 4. Recycling and Use of Low-Emission Vehicles: The Oregon Department of Transportation (ODOT) started various e-recycling and low emission vehicle programs (ODOT, 2013); 5. Use of "green" materials: The Florida Department of Transportation (FDOT) and Georgia Department of Transportation (GDOT) developed research facilities in order to elevate the green material technology in transportation infrastructure and focused on Asphalt pavement (Jim Warren, 2013).

Similarly, the Illinois Department of Transportation focuses on alternative fuel and electric vehicle initiatives (IDOT, 2013); and 6. Other initiatives: States with a smaller population and budget have also implemented numerous sustainable initiatives that enhance the state's green efficiency. The Wisconsin Department of Transportation (WIDOT) constructed a historical museum on transportation to educate people about the importance of sustainable transportation. Also, they have implemented an air quality program that focuses on reducing toxic generated from fuels. The West Virginia Department of Transportation (WVDOT) runs a tire-recycling program and plants wildflower (WVDOT, 2013).

IX. Sustainability Rating System

Sustainability rating systems are generally designed to perform a specific function, for specific projects and repairs, and to achieve specific goals. The rating systems can also be categorized into the region(s) of application, namely, international and national (Table 1), state (Table 2), and community levels (Table 3).

Table 1: National level rating systems and their developers

Sustainability rating system	Developers
Envision	Institute of Sustainable Infrastructure (ISI)
Sustainable highway self-evaluation tool	Federal Highway Administration (FHWA)
LEED	US Green Building Council (USGBC)
SITES	American Society of Landscape Architects (ASLA)
Green highway partnerships	U.S. Environmental Protection Agency (EPA)
CEEQUAL	Institution of Civil Engineers (ICE)

Table 2: State level rating system and their developers

Sustainability rating system	Developers
Green roads certification	Washington Department of Transportation and the University of Washington
GreenLITES certification	New York Department of Transportation
I- Last	Illinois Department of Transportation
BE2ST	Wisconsin Department of Transportation and the University of Wisconsin.

Table 3: Local, sustainable rating systems and their developers

Sustainability rating system	Developers
Sustainable transportation and analysis rating systems(STAR)	Portland Department of Transportation, Oregon
PEACH Roads	Cobb County, Georgia

Table 4: Categories of various rating systems Source: (Hirsch, 2011)

	Rating Systems				
	STAR	GreenLITES	Envision	I-LAST	Greenroads
Categories	Integrated Process	Sustainable sites	Project pathway/siting	Planning	Basic program requirements
	Access	Water quality	Project strategy	Design	Environment &water
	Climate	Material resources	Communities	Environmental	Access & equity
	Ecological function	Energy and atmosphere	Land use and restoration	Water quality	Construction activities
	Cost-effectiveness	Innovation	Landscaping	Transportation	Materials and resources
	Innovation	Planning	Ecology	Lighting	Pavement

X. Limitations of the Rating Systems

There are easily over 200 sustainable rating systems globally. Each rating system targets specific markets, regions, and products. Many rating systems are the products of public and private collaborations and are designated for different purposes at the national, state, and local levels. The rating systems categorize indicators into different technical areas. These areas target different environmental and social impacts such as habitat protection and enhancement, storm water management, material use, and reuse, context-sensitive design, light pollution, noise abatement, public outreach, land use compatibility, and construction waste reduction (Dondero, George, 2012). The rating system is one of the most common approaches for benchmarking and quantifying sustainability practices (for example, LEED and Envision). The output of the rating systems can be used to measure the different levels of sustainability, and thus speed up the process of sustainability implementation and adoption among the states with quantitative numbers and published examples.

The use of the systems depends on the market; the systems are designed. The systems can be generic, regionally specific, and even corporate specific. These systems are generally driven by the following:

a) Cost efficiency and effectiveness of the rating system

The rating systems are developed by pioneers either in the civil engineering field or by external agencies. Cost-effectiveness and sustainability are not correlated, and the results are still debatable with high investments on the rating systems. Most of the decision-makers ignore the sustainable factors unless they realize there are some cost savings out of it (Hirsch, 2011). The developers of rating systems should focus on the cost-effectiveness of their rating systems and has to develop a framework to analyze the cost-effectiveness (Hirsch, 2012).

b) Level of complexity in the rating system

This is an essential factor for the shortfall of the rating system. Rating systems are developed in order to certify, enhance, and encourage humans to adopt and achieve sustainability in various infrastructures. However, there are conventional approaches to appraising or valuing land/ buildings and analyzing property values in each country, although it appears that rating tools have not followed similar approaches; they are complex systems that are not easily accessible by the general public (Reed, 2009).

c) Specification of the rating system and their integration with the transportation projects

There are numerous rating systems developed in different parts of the world according to their specific climate change and business objectives. The rating systems have similar specifications with different categorizations with the project requirements. This, in turn, has created complications for stakeholders, including property investors. An understanding of the many differences between each market has been increasing difficulty (Reed, 2009).

Many sustainability-rating systems have become irrelevant, while others continue to thrive. Many of the thriving programs that have been developed specific to an organization's operations, environmental needs, local context, and sustainability philosophy, and thus they are still being used extensively (Hirsch, 2011). While these systems give more weight to the environmental credits (such as stormwater, habitat, vegetation, material use), they focus less on the equity and economic benefits. The key reason for this is that the cost-effectiveness of sustainability often overwhelms social relevance (Dondero, George, 2012). Economic decisions are far more important drivers of choices than what the public and private sectors make.

These rating systems often face a dilemma like:

1. Justify the weights and allocates points of the indicators.
2. Ensure the consistency of the evaluation process; and
3. Neglect the use of reliable information and data.

According to AASHTO, FHWA's self-evaluation tool (Invest) for sustainable highways does not focus on all three sustainable pillars. One particular critique noted that several concepts and modules overlapped one another, and the tools failed to clarify the intended linkages between the modules. The overlapping and unclear linkages result in potential double-counting of credits. (Eisenman, 2012).The table shows different points on traffic-related activities. The table shows that these systems allocate the emissions factor less weight. Also, the "multi transit factors" that involves ridership has very low weightage (as shown in the following table). In summary, points allocated in the rating systems only reflect the compliances of the rating systems, and compliance with systems does not necessarily mean achieving the intended sustainability goals of the systems. One of the purposes of this research is to examine the approaches that could better align with sustainability goals with various sustainability policies and practices.

Table 5: Traffic-related points on different rating systems Source: (Bockisch, 2012)

Category	Invest (%)	Envision (%)	Green Roads (%)	PEACH Roads (%)
Transportation planning	12	13	5	6
ITS	4	5	5	19
Multi Transit	4	4	8	3
Intermodal	6	0	0	2
Safety	9	2	2	0
Emissions	0	5	4	2
Total	35	29	24	32

XI. Issues in Sustainable Transportation

Sustainability in transportation addresses the basic needs of societies such as safety and is in a manner consistent with the health of humans and the ecosystem through transportation infrastructure. Sustainability aims to build up the social and environmental equity within and between generations. (AASHTO, 2009). The nature and scope of the issues and their implications for transportation planning and policy are only beginning to be explored in recent decades by scientists (Litman, 2006). The development of sustainable transport policies implies reconciling environmental, social, and economic objectives and will require further improvements to a wide range of fronts for inland transport (ECMT, 2000). The critical issues of policy-making include accidents, employment rates, accessibility, congestion, traffic growth, nature, emission, and air quality issues (ECMT, 2000). Land use pattern is also a significant barrier in achieving sustainability in transportation.

There is a significant relationship between transportation modes and energy consumptions per capita. Railways carry more goods and people and use less energy than trucks and planes (Lewis , 2009). Sea freights can carry much more loads and uses less fuel than railways, while air transportation consumes the most substantial amount of energy per ton of goods carried (UNCTAD, 2006). While public transportation consumes a lower energy footprint per capita compared with private transportation, availability and convenience often force people to rely on private transportation and results in lower ridership of transportation in many parts of the country, which increases energy use of such modes (Turtenwald, 2013).However, the economy cannot function properly without any of the above transportation modes. Perishable cannot rely on sea freight while shipping large quantities of electronics can be expensive using air freight. The decision to use the different types of transportation modes is often driven by economic needs rather than the sustainability of the modes.

XII. Sustainable Indicators

Sustainability indicators have to represent and measure the social, economic, and environmental status or condition of a transportation system. Indicators simplify the measurement of sustainability and to overcome the complexities of quantifying sustainability (Bossel, 1999). Sustainability indicators also simplify the process of answering the question of how to reduce human impact and conserve for future generations (Oswald, 2008). The indicators must be selected according to the rigor of any research process, and any models generated from the research have to be based on reliable information. According to Bossel (1999), the indicators are selected based on four steps: 1.Understand the requirement and the total system; 2.Identify the potential indicators; 3. Quantify the indicators; and 4.Construct a participative process. Sustainability policies and practices will be evaluated into the next level if a set of measurable indicators can be used to track trends, compare areas and activities, evaluate particular policies and planning options, and set performance targets (Litman, 2011).

The indicators adopted for measuring sustainability are determined by their level of importance to their purposes. A progress report prepared by the U.S. Interagency Working Group (IAWG) on Sustainable Development Indicators highlighted that the approaches of developing these indicators. The report includes: (1) a proposed framework for measuring progress towards sustainable development; (2) a set of 40 specific indicators for the U.S. within that framework; and (3) time-series data and graphs of each indicator. (Henrik Gudmundssun, 2001). Significant elements in the report are from the 17 indicators listed in the report indicate favoritism towards Sustainable Development, 13 indicators showed the opposite, and ten indicators had unclear interpretations (Henrik Gudmundssun, 2001). Some of the indicators are treated separately, and new indicators are developed to reflect the needs.

XIII. Level of Importance

There are many conditions in the transportation system that influences sustainable indicators. The indicators for the preliminary analysis are selected based on the eight principles of a good rating system that Litman (2011) indicated. These indicators include Budget, Ridership, Emission, Consumption, and Energy efficiency (BRECE). Each of these indicators includes a wide range of sub-indicators that influences sustainability and is interrelated and interdependent on one other. Table 4.8 lists the various sub-indicators that come under the BRECE indicators.

The level of importance of each indicator used by the system is determined by; (1) the availability and reliability of information and data sources; (2) the impact of the indicators on the state sustainability; (3) how the indicators influence states' decisions to implement them; and (4) the impact of the indicators on the transportation sector. The sustainable indicators are ranked high, medium, and low based on various factors such as availability of the data, and their importance to the research. For example, budget is an essential indicator with the focus since it involves many relations with other indicators like population and population density of the state. Similarly, ridership on-demand response has very fewer data and can be neglected. Hence, it is of low importance. The bicycle path program is one crucial sustainable initiative that is implemented almost in every state, but the data availability of the bicycle program is qualitative rather than quantitative, hence it is considered of medium importance. The table shows the various indicators and their grouping, respectively.

Table 6: Budgets on transportation (Sunshine review, 2010)

Budget		
Sustainable indicators	Data sources	Importance
Total state budget	Sunshine Review	High to Medium
Total budget on transportation	Sunshine Review	High to Medium
The budget on public transportation	Sunshine Review	High to Medium
The budget on sustainable programs	Sunshine Review	High to Medium
The budget for sustainable research	Sunshine Review	High to Medium

Table 7: Ridership on public transit(APTA, 2011)

Public transportation		
Sustainable indicators	Data sources	Importance
Ridership of public transport	American Public transit Association (APTA)	High to Medium
Ridership on high-speed rail	American Public transit Association (APTA)	High to Medium
Ridership on commuter rail	American Public transit Association (APTA)	High to Medium
Ridership on buses	American Public transit Association (APTA)	High to Medium
Ridership on carpool/vanpool	American Public transit Association (APTA)	High to Medium
Ridership on trolleybuses	American Public transit Association (APTA)	High to Medium
Ridership on streetcars	American Public transit Association (APTA)	Medium to Low
Ridership on bicycle	American Public transit Association (APTA)	Medium to Low
Ridership on demand response	American Public transit Association (APTA)	Low

Table 8: Emissions and fuel consumption indicators(EIA, 2010)

Emissions and fuel consumption		
Sustainable indicators	Data sources	Importance
Carbon emissions by public transportation	Energy Information Administration (EIA)	High to Medium
Carbon emissions by state buildings	Energy Information Administration (EIA)	High to Medium
Gasoline consumption	Energy Information Administration (EIA)	High to Medium
Ethanol consumption	Energy Information Administration (EIA)	High to Medium
Biofuel productions	Energy Information Administration (EIA)	High to Medium

Table 9: Energy use and efficiency indicators(FHWA, 2010)

Energy use and efficiency		
Sustainable indicators	Data sources	Importance
Transportation energy	Energy Information Administration (EIA)	High to Medium
Operational energy	Environmental Protection Agency (EPA)	High to Medium
Embodied energy	Environmental Protection Agency (EPA)	High to Medium
State vehicles on alternative fuels	Energy Information Administration (EIA)	High to Medium
State vehicles on electricity	Federal Highway Administration (FHWA)	High to Medium

Number of alternative fuel stations	Energy Information Administration (EIA)	High to Medium
Number of electric charging stations	Energy Information Administration (EIA)	High to Medium
Renewable energy in public transit	Energy Information Administration (EIA)	High to Medium
Public buses running on electricity	Energy Information Administration (EIA)	Medium to Low

Table 10: State agencies' commitments and goals

Commitment by state agencies		
Sustainable indicators	Data sources	Importance
Sustainability targets	DOT/Survey	High to Medium
Participation in livability programs	DOT/Survey	Medium to Low
Public involvement and educational programs	Survey	Highto Medium
Environment management systems by state DOTs	Survey	High to Medium
Green highway initiatives	DOT/Survey	High to Medium

Table 11: Other important indicators

Proposed other important indicators		
Sustainable indicators	Data sources	Importance
Land used on highways	Web sources	High to Medium
Recycling and reuse of materials	Survey	Medium to Low
Recycling rate by state agencies	Survey	Low
State Water Quality	Web sources	Low
Water use by the state transportation agency	Web sources/Survey	Medium to Low
Total number of OSHA violations	Web sources/Survey	High to Medium
State overall air quality	Web sources/Survey	Low
Vehicle toxicity emission	Web sources	High to Medium
Construction pollutants	Web sources/Survey	Medium to Low
Vehicle emissions inspection	EIA/Survey	High to Medium
Particulate emissions	EIA/Survey	High to Medium
Productivity loss due to injury	Survey	High to Medium
Productivity loss due to death	Survey	High to Medium
Project delay	Survey	High to Medium

XIV. Selection of Indicators

Several vital indicators were dropped from the framework due to (1) the lack of available and reliable data, and (2) information for those indicators are difficult to verify or that the government agencies are not able to provide such data for the Survey. Examples of the "drop-out" indicators include "the impact of transportation on the standard of living,""quality of life,""health and crime,"and "how the community felt about various transportation projects."For example, the overall funding allocated for sustainability-related initiatives is not available in most of the states and dropped as a factor at this time. The research team needs to focus on other important indicators. Data availability of the embodied and operational energy of state buildings is also not available and has to be omitted. Carbon emissions from the state buildings require time to collect; hence the indicator is neglected at this time. Instead of tracking health statistics (were establishing a link between transportation and health can be very difficult), the research team targets pollutant emissions. It is challenging to correlate health issues with transportation issues. The research team also included the ridership on-demand response as a sub-indicator because of the availability of data for all fifty states though it has very less quantifiable values.

The Environmental Protection Agency has not established procedures to track the entire transportation indicator sets continuously. Some of the examples of environmental indicators related to transportation are criteria air pollutants, toxic pollutants, greenhouse gases, chlorofluorocarbons, and stratospheric ozone depletion, habitat and land use, water quality, hazardous materials incidents, noise and solid waste (Henrik Gudmundssun, 2001).There are many conditions in the transportation system that influences sustainable indicators. The indicators for the preliminary analysis are selected based on the eight principles of the excellent rating system mentioned in Litman(2011)that fits the research at its best at this point. These indicators can be presented as Budget, Ridership, Emission, Consumption, and Energy efficiency (BRECE). Each of these indicators includes a wide range of sub-indicators that influences sustainability and is interrelated and interdependent. Table 12 lists the various sub-indicators that come under the BRECE indicators.

Table 12: Selection of Indicators (BRECE)

Sustainable indicators	Importance
Total state budget	High to Medium
Total budget on transportation	High to Medium
The budget on public transportation	High to Medium
The budget on sustainable programs	High to Medium
The budget for sustainable research	High to Medium
Ridership of public transport	High to Medium
Ridership on high-speed rail	High to Medium
Ridership on commuter rail	High to Medium
Ridership on buses	High to Medium
Ridership on carpool/vanpool	High to Medium
Ridership on trolleybuses	High to Medium
Ridership on streetcars	Medium to Low
Ridership on bicycle	Medium to Low
Ridership on demand response	Low
Carbon emissions by public transportation	High to Medium
Transportation energy	High to Medium
Gasoline consumption	High to Medium
Ethanol consumption	High to Medium
Biofuel productions	High to Medium
Number of electric charging stations	High to Medium

BRECE indicators comprise of sub-indicators that are selected based on the reliability of information sources, data availability, and the importance of the indicator as analyzed by the preliminary analysis on sustainable transportation. These indicators are statistically proven to be positively correlated using different statistical concepts. The concepts include Karl Pearson's population coefficient correlation, p-value analysis, and Spearman's rank correlation. The correlation is determined manually and rechecked for accuracy using Minitab statistical software tool. Apart from the quantitative data, the research team focused on using qualitative information available online from reliable sources. These qualitative data include the documents, proposed plans and initiatives, and reports on environmental prevention strategies by DOTs.

XV. Statistical Analysis

Two adjustors, population and GDP, are used to adjust the indicators. Population influences the sustainability of transportation, at least on the level where public transportation becomes viable. It is used as a key adjuster with which the data collected from various trusted sources are adjusted to reflect the ranking of the states. The population of the state reflects the demand for public transport. States generally spend more money on transportation if it has a greater population density. Large states have more giant footprints, and thus it is necessary to present the sustainability after adjusting the size of the states. Population and budget are good adjustors. The various indicators that are used with population adjustors are the total number of vehicles registered, total transportation budget, the population density of state and most significant cities, and ethanol and gasoline consumption. Three different analyses are done with the population and GDP as an adjuster.

A data analysis framework is developed to lay out the relationship between the data and their intended output. The data are gathered from various trusted sources and then grouped under BRECE indicators. The adjustors used in this research are the population and GDP. Pearson's correlation and P-value are determined using the Minitab statistical tool.

The various equations used to determine the correlations are as follows

1. Pearson's population coefficient equation is given by (Source: Social science statistics)

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

2. Rank correlation is given by (Source: Social science statistics)

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}.$$

The correlation coefficients and P-value is determined through manual calculation and statistical package. The top ten states of each indicator are selected before and after adjustments for the correlation analysis. Pearson's correlation and P-value are determined before adjusting the indictors through the population, and the rank correlation is determined after adjustment. It is found that the values are in the range of -1 to +1, which proves the indicators grouped and adjusted are positively correlated. The level of an importance checkbox is also added to the table to explain how the indicators are treated with respect to population and GDP. The level is selected based on the impact of such indicators on sustainable transportation concerning real-time factors. Table 13 below shows the correlation values of indicators adjusted through the population.

Table 13: Correlation values of indicators adjusted through population

Statistical Analysis					Level of Importance		
S. No.	Indicators	Pearson's correlation	Rank correlation	P-value	High to Medium	Medium to Low	Low
1	Transportation Budget	0.462	0.81	0.179	☐	☒	☐
2	Automobiles	0.568	0.40	0.011	☒	☒	☐
3	Ridership	0.472	0.64	0.582	☒	☐	☐
4	Carbon emission	0.303	0.18	0.069	☒	☐	☐
5	Ethanol Consumption	0.311	0.93	0.035	☐	☒	☐
6	Gasoline consumption	0.314	0.36	0.020	☒	☐	☐
7	Transportation energy consumption	0.310	0.24	0.013	☒	☐	☐

The transportation budget does not directly relate to sustainability. The budget for the population is essential to understand the requirement of implementing policies and standards, Hence it of medium importance. Carbon emissions contribute to environmental safety to a greater extent, and hence it is of higher importance.

Gross Domestic Product plays a vital role and is considered to be the primary indicator of the economic health of a nation. Wealthier states tend to spend relatively more money on their investments than weaker states on GDP reflects the cost of living (Kimberly Amadeo, 2013). Similarly, the correlation values of the indicators are determined by adjusting through GDP. Since budget and GDP are in the same units, the budget is not adjusted through GDP. Table 2 shows the correlation values for the indicators adjusted through GDP. As population adjustment, the correlation values are positive. When looking at the importance of indicators, budget and ridership are not of high importance when adjusted through GDP, whereas consumption is of high importance. Hence the data adjustments are proved to be the right way for the data analysis to be continued.

Table 14: Correlation values for the indicators adjusted through GDP

Statistical Analysis					Level of importance		
S. No.	Indicators	Pearson's Correlation	Rank correlation	P-value	High to Medium	Medium to Low	Low
1	Budget	NA	NA	NA	☐	☐	☐
2	Automobiles	0.888	0.18	0.001	☐	☒	☐
3	Ridership	NA	NA	NA	☐	☐	☐
4	Carbon emission	0.056	0.18	0.743	☒	☐	☐
5	Ethanol Consumption	0.021	0.55	0.934	☒	☐	☐
6	Gasoline consumption	0.056	0.43	0.778	☒	☐	☐
7	Transportation energy consumption	0.871	0.23	0.001	☒	☐	☐

The table shows some interesting facts on the positive correlation and their importance. The level of importance varies when adjusted through population and GDP. The correlation with GDP and transportation budget cannot make any sense as both involve the same units, which is U.S dollars. Similarly, the ridership per GDP is not considered to be a better analysis by the authors. The P-values are used to determine the testing of significance between two indicators and thus lower the p-value, higher the chance of correlation to be negative. It is noted that automobiles by GDP have lesser P-value after adjustment, which can say the correlation and the performance analysis can hit different opinions on the outputs. The focus of this paper is to prove that sustainable indicators are positively correlated, which are grouped under BRECE, and this research has a more significant potential of performance analysis, including several indicators under different categories.

XVI. Conclusion

Sustainability requires more comprehensive and integrated planning, which accounts for a broad set of economic, social, and environmental impacts, including those that are difficult to measure (Litman, 2006). Sustainable development of a state mainly depends on how they conserve energy, land, and other natural resources. The social and economic status of the state varies often, and the energy use, consumption, and production depend on the population of the state. Thus, the strategy and combination of factors need to be developed as a sustainable rating framework in order to quantify the benefits rather than rating it through the point system that still has several questions unanswered. Figure 1 shows the positive correlation values of the indicators.

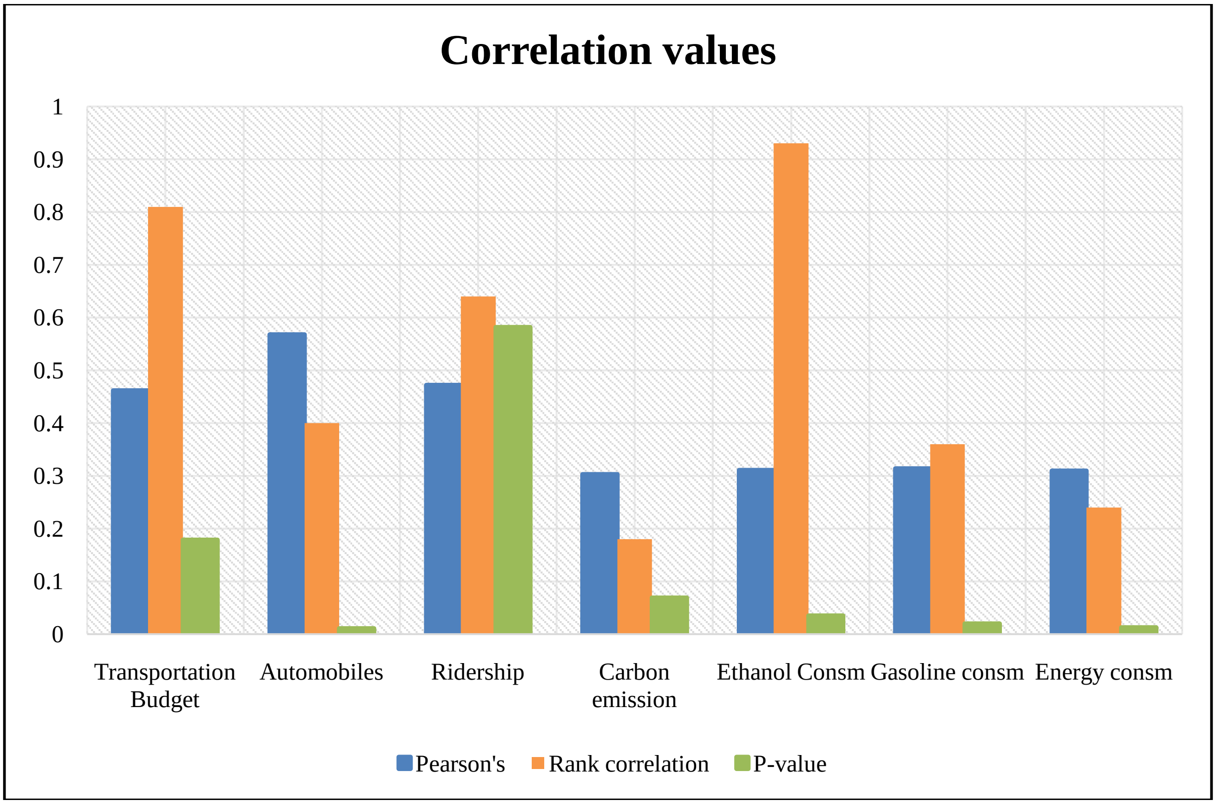

Figure 1: Correlation values of the indicators

The sustainable indicators are categorized into conventional, comprehensive, and straightforward patterns, which have their limitations with various real-time factors (time and population). There is no evidence of these indicators to be the right indicators of sustainability though it is environmentally related. This paper relates the sustainable indicators and proves statistically that these are the efficient indicators that can be used for analyzing the sustainable efficiency of the transportation sector.

The main objectives of this state are met along different sections of this paper, which includes fundamental practices, impacts of three pillars, sustainable indicators, and relationship among the sustainable indictors. The next step of this research is to understand more interrelationships of policies and sustainable transportation systems and to create a database technology where the user can populate the data values to understand the sustainable performances of their state. This can be further developed as a web-based system and can be implemented on states, counties, and cities for a more in-depth analysis of sustainable performances.

References Références Referencias

1. AASHTO. (2009, May 27). Sustainable peer exchange. Retrieved from Center for environmental excellence: http://environment.transportation.org/pdf/sustainability_peer_exchange/AASHTO_SustPeerExh_BriefingPaper.pdf
2. Adjo Amekudzi, C. M. (2005). Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. Journal of Infrastructure system, 31-50.
3. Alameda County Transportation comission. (2009). ISSUE PAPER: Transportation Demand Management and Parking management. Alameda County.
4. Andrea, S. (2013, Apr 17). Overview of Knowledge management. Retrieved Aug 20, 2013, from University of Kentucky: http://www.uky.edu/~gmswan3/575/Serban_and_Luan_2002.pdf

5. APTA. (2011). Public transportation ridership report. Washington: APTA.
6. Bockisch, J. (2012, July). Transportation sustainability rating system. Retrieved May 16, 2013, from Gresham smith and partners: http://www.gaite.org/wp-content/uploads/2012/07/GAITE-Presentation-Sustainability-July-2012.pdf
7. Bossel, H. (1999). Indicators for sustainable development: Theory, method, applications. Winnipeg: International Institute of Sustainable Development.
8. Burwell, T. L. (2006). Issues in sustainable transportation. International Journal of Global Environmental Issues, 331-347.
9. Caltrans. (2013, Jul 12). California Transportation. Retrieved Sep 6, 2013, from California Department of Transportation: http://www.dot.ca.gov/
10. CH2M HILL. (2009, May 27). Transportation and sustainability best practices background. Retrieved from Sustainability peer exchange: http://environment.transportation.org/pdf/sustainability_peer_exchange/AASHTO_SustPeerExh_BriefingPaper.pdf
11. Cobb County. (2013). PEACH Roads. Retrieved Aug 5, 2013, from the Cobb County Department of Transportation: http://portal.cobbcountyga.gov/images/documents/dot/projects/peach_roads_handout_april2013.pdf
12. D. Banister, J. P.-G. (2007). Making Sustainable transport politically and publically acceptable. Cheltenham: Edward Elgar Publishing.
13. Daniel. (2011). Sustainable Transport Evaluation. Eschborn, Germany: Federal Ministry of Environment.
14. Dearing. (2000). Technologies are supportive of sustainable transportation—annual energy review.
15. Dondero. (2012). Developing A Comprehensive Sustainable Transportation Analysis Framework. Santa Cruz: Santa Cruz County Regional Transportation Commission.
16. Dondero, G. (2012, Nov 15). Developing A Comprehensive Sustainable Transportation Analysis Framework. Retrieved from http://sccrtc.org/wp-content/uploads/2010/12/TRB-STARS-Paper-121115-GD-revision.-Final.pdf
17. Dondero, George. (2012, Nov 15). Developing a Comprehensive Sustainable Analysis Framework. Retrieved May 15, 2013, from SCCRTC: http://sccrtc.org/wp-content/uploads/2010/12/TRB-STARS-Paper-121115-GD-revision.-Final.pdf
18. ECMT. (2000). Sustainable transport policies. European Conference of Ministers of Transport (p. 38). Paris: OECD.
19. EIA. (2010, Dec 8). EIA. Retrieved May 18, 2013, from U.S Energy Information Administration: http://www.eia.gov/oiaf/1605/ggrpt/carbon.html#transportation
20. Eisenman, A. A. (2012, May). Sustainable Streets and Highways: An Analysis of Green Roads Rating Systems. Retrieved Jun 20, 2013, from http://www.utc.gatech.edu: http://www.utc.gatech.edu/sites/default/files/projects/reports/eisenman_ana_a_201205_mast_sustainable_streets_and_highways.pdf
21. Envision. (2013, Jul 23). Envision, Sustainable infrastructure rating system. Retrieved Aug 21, 2013, from the Institute for sustainable infrastructure: http://www.sustainableinfrastructure.org/rating/index.cfm
22. FHWA. (2007, Septemeber 2). Transportation planning process, Key issues. Retrieved Aug 18, 2013, from Department of Transportation: http://www.planning.dot.gov/documents/briefingbook/bbook.htm
23. FHWA. (2010). Highway statistics series. RetrievedMay 14, 2013, from FHWA: http://www.fhwa.dot.gov/policyinformation/statistics/2010/hm20.cfm#foot1
24. Flaper, T. (2009, Mar 2). Three Bottom line. RetrievedMay 12, 2013, from Indiana Business Research Center: http://www.ibrc.indiana.edu/ibr/2011/spring/pdfs/article2.pdf
25. Gelos, G., & Ustyugova, Y. (2011). Inflation responses to commodity price shocks – how and why do countries differ? International Monetary Fund Economic Review: Commodity Price Volatility and Inclusive Growth in LICs, (pp. 1-31). Washington, D.C.: International Monetary Fund.
26. Goldman, R. (2006). Sustainable urban transport: Four innovative directions. Technology in Society, 261-273.
27. Greenroads. (2012, Nov 15). Retrieved May 12, 2013, from www.greenroads.org: https://www.greenroads.org/1429/browse-the-online-manual.Html.
28. Henrik Gudmundssun. (2001, Jun 12). National Environmental Research Institute. Retrieved from Department of Policy analysis: http://www2.dmu.dk/1_viden/2_publikationer/3_arbrapporter/rapporter/ar148.pdf
29. Hirsch. (2012, Mar9). The Development of Cost-Effective Sustainability Programs and Rating Systems. Retrieved Aug 21, 2013, from Terralogic Solutions: http://terralogicss.com/sustainable-transportation/the-development-of-cost-effective-sustainability-programs-and-rating-systems
30. Hirsch, A. (2011, Jul 12). Terralogics Sustainable solution. Retrieved May 12, 2013, from terralogicss.com: http://terralogicss.com/_blog/Sustainable_Transportation/post/Summary_of_Transportation_Sustainability_Rating_System_Programs/
31. IDOT. (2009, February 29). I-LAST. Retrieved May 15, 2013, from www.dot.state.il: http://www.dot.state.il.us/green/documents/I-LASTGuidebook.pdf

32. IDOT. (2013, August 12). IDOT Green initiatives. Retrieved August 20, 2013, from dot.state.il.u: http://dot.state.il.us/green/documents.html
33. IPTV. (2004, Jul 8). Fossil fuels. Retrieved Aug 20, 2013, from Iowa Public television: http://www.iptv.org/exploremore/energy/profiles/fossil_fuels.cfm
34. Jim Warren. (2013, Jun 12). SIS Performance. Retrieved Aug 18, 2013, from FDOT: http://www.dot.state.fl.us/planning/performance/SIS-Performance.pdf
35. Kimberly Amadeo. (2013, Aug 10). U.S. Economy. Retrieved Sep 6, 2013, from U.S. Economy: http://useconomy.about.com/od/grossdomesticproduct/p/GDP.htm
36. Langfang. (2010). TRACKING THE LIFE CYCLE OF CONSTRUCTION STEEL: DEVELOPING A RESOURCE LOOP. Lawrence: KUSCHOLARWORKS.
37. Larcinese. (2004). Allocating the U.S. Federal Budget to the States:. Retrieved May 12, 2013, from http://personal.rhul.ac.uk/ulte/108/papers/jopltr.pdf
38. Lewis. (2009, Apr 7). Rail Transport in Greek and Roman World. Retrieved Aug 20, 2013, from Wikipedia: http://www.sciencenews.gr/docs/diolkos.pdf.
39. Litman. (2006). Issues in sustainable transportation. Internation Journal of Global environmental issues, 331-347.
40. Litman. (2011, Feb 11). Developing Indicators for Comprehensive and sustainable transportation. RetrievedMay 10, 2013, from Victoria transport policy Institute: http://www.vtpi.org/sus_tran_ind.pdf
41. Litman, T. (2012, Sep 10). Evaluating Transportation land use impacts. Retrieved from Victoria transportation policy institute: http://www.vtpi.org/landuse.pdf
42. NMDOT. (2013, Jul 12). The intelligent transportation system. Retrieved Aug 13, 2013, from NMDOT: http://www.dot.state.nm.us/content/nmdot/en.html
43. NYSDOT. (2012, July). Green LITES. Retrieved May 12, 2013, from NYSDOT: https://www.dot.ny.gov/programs/greenlites
44. NYSDOT. (2013, Apr 12). Green and Blue Highways. Retrieved Sep 6, 2013, from New York Department of Transportation: https://www.dot.ny.gov/divisions/operating/oom/transportation-maintenance/green-blue-highways
45. ODOT. (2013, Aug 11). Sustainability Programs. Retrieved Sep 6, 2013, from Oregan Department of Transportation: http://www.deq.state.or.us/programs /sustainability/
46. OECD. (2000, Jul 12). Sustainable Transportat policies. Retrieved Sep 13, 2013, from OECD: http://internationaltransportforum.org/pub/pdf/00Sustain.pdf
47. Oswald, M. (2008, August). Rating The Sustainability Of Transportation Investments. Delaware, Delaware, United States.
48. Reed, R. (2009). International comparison of Sustainable rating tools. JOSRE, 1-22.
49. Riche, F. M. (2010). The United States of America Developing Key National Indicators. U.S. Government Accountability Office, Key National Performance Indicators. Washington D.C.: U.S. Government Accountability Office. Retrieved from http://www.gao.gov/npi/usadkni.pdf
50. Rodrigue, J.-P. (2013). Transportation and Energy. Retrieved Aug 20, 2013, from The Geography of Transportation: http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c2en.html
51. Simons, J. A. (1987, Jun 19). Maslow's hierarchy of needs. Retrieved Aug 20, 2013, from Wayback Machine: http://web.archive.org/web/20100211014419/http://honolulu.hawaii.edu/intranet/committees/FacDevCom/guidebk/teachtip/maslow.htm
52. STAR. (2012). STAR rating systems. Retrieved May 14, 2013, from STAR: http://www.transportationcouncil.org/about-stars
53. Sunshine review. (2010). Retrieved May 11, 2013, from Sunshine review: http://sunshinereview.org/core/state-budgets/
54. TRB. (2005). Integrating sustainability into the transportation planning process. Introducing Sustainability into surface transportation planning (pp. 1-71). Baltimore: TRB.
55. Turtenwald, K. (2013, APR 12). Public transport vs Private Transport. Retrieved Aug 21, 2013, from public transportation: http://www.ehow.com/list_7691830_differences-between-public-private-transportation.html
56. TxDOT. (2013, Jun 11). Texas Department of transportation. Retrieved Sep 5, 2013, from Texas Department of transportation: http://www.txdot.gov/
57. U.S DOT. (2008, 08 23). American Driving Reaches Eighth Month of Steady Decline. Retrieved 09 11, 2013, from U.S DOT: http://www.fhwa.dot.gov/pressroom/fhwa0817.cfm
58. UNCTAD. (2006, Jun 11). Review of Maritime Transport. Retrieved Aug 17, 2013, from United Nations Conference on Trade and Development: http://unctad.org/en/docs/rmt2006_en.pdf
59. UNSD. (2011, June). UNSD Environmental Indicators. (U.N. Department of Economic and Social Affairs) RetrievedMay 10, 2012, from United Nations Economic and Social Development Home: http://unstats.un.org/unsd/environment/qindicators.htm
60. UNSDa. (2012, Mar 10). Social Indicators. Retrieved May 10, 2012, from Economics and Social Development Home: http://unstats.un.org/unsd/demographic/products/socind/

61. WVDOT. (2013, Jun 12). Operation Wildflowers. Retrieved Sep 6, 2013, from West Virginia Department of Transportation: http://www.transportation.wv.gov/highways/maintenance/wildflowers/Pages/default.aspx

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Seismic Hazard and Total Risk of Existing Large Dams in the Marmara Basin, Turkey

By Hasan Tosun
Osmangazi University

Abstract- Safety evaluation is a fundamental stage of existing dams and their appurtenant structures, which have a high-risk potential for downstream life and property. Turkey is a country, which seismically settled at one of the most active regions in the world, and earthquakes with high magnitude frequently occur here. There are some regions, which are severely under threatening of earthquakes. One of them is the Marmara region with twenty-four million people. This region, namely the Marmara basin, has at least forty-five large dams with different types. This study considered nineteen of them to relieve their seismic hazard parameters for all dam sites and total risk for each structure. The study area is lying in a seismically, very active part of Turkey. The southern part of the basin is structurally cut by the North Anatolian Fault, which is a famous structural feature that produces deathful earthquakes, and its offshoots. The analyses have indicated that peak acceleration widely ranges for the nineteen dam sites of this basin. The total risk analyses have concluded that most of the dams in the metropolitan area have high-risk classes and a significant effect for public safety.

Keywords: *dam, earthquake, seismic hazard, total risk.*

GJRE-E Classification: *FOR Code: 090599*

SEISMICHAZARDANDTOTALRISKOFEXISTINGLARGEDAMSINTHEMARMARABASINTURKEY

Strictly as per the compliance and regulations of:

Seismic Hazard and Total Risk of Existing Large Dams in the Marmara Basin, Turkey

Hasan Tosun

Abstract- Safety evaluation is a fundamental stage of existing dams and their appurtenant structures, which have a high-risk potential for downstream life and property. Turkey is a country, which seismically settled at one of the most active regions in the world, and earthquakes with high magnitude frequently occur here. There are some regions, which are severely under threatening of earthquakes. One of them is the Marmara region with twenty-four million people. This region, namely the Marmara basin, has at least forty-five large dams with different types. This study considered nineteen of them to relieve their seismic hazard parameters for all dam sites and total risk for each structure. The study area is lying in a seismically, very active part of Turkey. The southern part of the basin is structurally cut by the North Anatolian Fault, which is a famous structural feature that produces deathful earthquakes, and its offshoots. The analyses have indicated that peak acceleration widely ranges for the nineteen dam sites of this basin. The total risk analyses have concluded that most of the dams in the metropolitan area have high-risk classes and a significant effect for public safety.

Keywords: dam, earthquake, seismic hazard, total risk.

I. Introduction

The ratings of seismic hazard of the dam site and the risk potential of the structure are the main factors acting on public safety for downstream life. The peak ground acceleration, derived from the design earthquake that produces the seismic loads, is a mainly used criteria of the seismic hazard of a dam site. The dam height, reservoir capacity, potential downstream damages and evacuation requirements are the parameters for assessing risk rating of the dam. Tosun (2012) states that risk evaluation utilized the structure characteristics and seismic hazard ratings separately. According to Bureau (2003), the total risk factor for dam structure should depend on together these two factors. Recently, the ICOLD (2016) has published the guideline for selecting seismic parameters for large dams.

Turkey is a country that desires to use land and water resources effectively. The total number of large dams constructed throughout the country is more than 1250. Most of them are of the embankment type. However, the number of concrete and rolled-compacted concrete dams increase recently. The dam design engineers in Turkey think that embankment dams are a suitable type for the sites having high seismic activity, when well compacted according to the specifications. However, the author states that strong ground shaking can result in instability of embankments of the earth and rockfills and loss of strength at the foundations, especially for dams that are under near-source effect. Author and co-workers have so many research studies for the structures discussed in the basin and neighboring areas (Tosun and Tosun, 2017a; Tosun, 2018; Tosun and Onder, 2018; Tosun et al. 2020). They also studied on river basin risk analysis and seismic hazard of large dams in Turkey (Tosun and Seyrek, 2010; Tosun, 2011; Seyrek and Tosun, 2011; Tosun, 2012; Seyrek and Tosun, 2013; Tosun, 2015; Tosun and Oguz, 2017; Tosun and Tosun, 2017b).

The study considers existing large dams in the Marmara basin, which covers lands around the Marmara Sea in Turkey (Fig.1). This basin has a surface area of 2.31 million ha with a water yield resources of 8.3 billion cu.m per year at the Northwest Anatolia. This study deals with an assessment of seismic hazard and total risk, and evaluates 19 large dams, which have a hydraulic height between 10.1 and 109.0 m, in the Marmara basin. Table 1 shows their technical characteristics. There are twelve large dams in the basin for providing domestic water to the Istanbul Metropolitan area in which seventeen million people are living. However, the existing dams in the Northern part of the basin, which were constructed by the Istanbul Water and Sewerage Administration, were excluded in this study because of being lack of data.

Author: Full Professor, Department of Civil Engineering, Osmangazi University, Eskisehir, Turkey. e-mail: htosun@ogu.edu.tr

Table 1: Technical characteristics of dams considered for this study (DSI, 2016)

#	Dam	Aim (*)	Height from river bed (m)	Completed Year	Type (**)	Volume of embankment (hm^3)	Volume of reservoir (hm^3)
1	Alibey	D+F	28.0	1983	EF	1.927	65.00
2	Armagan	I	57.5	1999	RF	1.560	51.50
3	Atikhisar	I+D+F	33.7	1973	EF	2.218	52.20
4	Bakacak	I	50.0	1998	RF	2.200	139.00
5	Bayramdere	I+D	56.0	2011	RF	1.000	18.45
6	Buyukçekmece	D	10.1	1987	EF	1.718	172.45
7	Cokal	I+D	57.0	2011	CFR	3.500	204.00
8	Darlık	D	73.0	1988	RF	1.600	107.00
9	Elmali II	D	42.5	1955	CG	0.103	10.31
10	Gokce	D	50.0	1989	EF+RF	0.133	21.71
11	Gokceada	I+D	33.0	1983	EF	0.560	16.80
12	Kadikoy	I+D+F	34.1	1973	EF	0.680	56.50
13	Kirazlıdere	D	109.0	1999	RF	5.200	60.00
14	Omerli	D	52.0	1972	EF	1.650	436.53
15	Sazlidere	D	23.0	1996	RF	1.780	131.50
16	Tasoluk	I	65.0	2009	RF	1.700	79.40
17	Tayfur	D	39.0	1985	RF	0.298	4.36
18	Umurbey	I	81.0	2003	EF	2.400	24.56
19	YeniceGonen	I+D+E+F	70.0	1997	RF+EF	2.400	227.04

(*) D: Domestic Water, E: Energy, F: Flood control, I: Irrigation and IU: Industrial use
(**) CFR: Concrete faced rock, EF:Earthfill, RF:Rockfill and CG:Concrete Gravity

II. Methods of Analysis

Seismic hazard is the main factor acting on the total risk of dam structures. The peak ground acceleration (PGA) is the parameter to be used in defining the seismic hazard of a dam site. For each dam site, author identifies all possible seismic sources and evaluates their potential in detail, as based on the guidelines (Fraser, 2002) and the unified seismic hazard modeling for the Mediterranean region introduced by Jiminez et al (2001). The extensive surveys and a search of available literature identify several energy sources to analyze the seismic hazard of dams in Turkey. The seismic hazard analyses also depend on the data instrumentally recorded earthquakes that occurred within the last 100 years. As summary, the study considers seismic zones and earthquakes within the area having a radius of 100 km around the dam site.

The seismic hazard study includes probabilistic and deterministic analyses. For dam sites, design engineers generally use the deterministic and probabilistic seismic hazard analyses. The deterministic seismic hazard analysis (DSHA) considers a scenario having a four-step process and provides a straightforward framework for the assessment of the worst ground motions. The probabilistic seismic hazard analysis (PSHA) defines a framework for uncertainties to identify and combine in a rational manner. DSHA takes into account geology and seismic history to identify earthquake sources and to interpret the strongest earthquake with regardless of time. In comparison, the PSHA considers uncertainties in size, location and recurrence rate of earthquakes (Kramer, 1996; Krinitzsky, 2005).

The study adopted various attenuation relationships to calculate the peak ground acceleration (PGA) acting on dam sites due to unavailability of strong motion records. This study primarily taken into account eight separate predictive relationships for horizontal peak ground acceleration (Campbell, 1981; Boore et al.1993; Ambraseys, 1995; Campbell & Bozorgnia, 1994; Boore et al. 1997; Gulkan & Kalkan, 2002; Kalkan & Gülkan, 2004; Ambraseys et al. 2005). However, the author excluded some data for the study because of giving extreme values.

International Commission on Large Dams (ICOLD) defined new terms, namely the Maximum Credible Earthquake (MCE) and the Safety Evaluation Earthquake (SEE), in its recently published documents (ICOLD, 2016). However, this study considers earthquake definitions given by Federal Emergency Management Agency (FEMA).This organization defines the Operating Basis Earthquake (OBE), the Maximum Design Earthquake (MDE) and the Safety Evaluation Earthquake (SEE) for different level of shaking (FEMA, 2005).In Turkey, there are so many examples analyzed by using these definitions in the past. (Tosun and Savas, 2005; Tosun, 2006; Tosun, 2007; Tosun and Turkoz, 2007; Tosun et al. 2007a, 2007b and 2007c; Tosun, 2008; Tosun and Seyrek, 2012; Tosun, 2015; Tosun & Tosun, 2017b). Recently, they pointed out that risk assessment is an important aspect for dams and their appurtenant structures (Tosun, 2019a; Hariri-Ardebeli et al. 2020).

III. Seismic Hazard Analyses

The analyses of seismic hazard in this context consider all possible seismic sources for dam sites in the Marmara basin based on the zonation map of Turkey, prepared by The National Disaster Organization and other Institutes for general use. The author and his co-workers modified it to use for dam projects. They considered seismic history and local geological features to quantify the rate of seismic activity in the basin. The detailed evaluation indicated that there are two-separated seismic zones in the related area.

In Turkey, The National Geological Survey released a new seismo-tectonic map to the public in 2013 (MTA, 2013). Fig.1also shows the study area on the national seismo-tectonics model. The ICOLD (2016) defined the near-field motion, which is ground motion recorded in the vicinity of a fault. This specification suggested a correlation between the radius of near field area and earthquake magnitude based on the cases in West United States. The author established limits of near-field motion for the investigation area. According to this model, there are eight dams, which are under the near-field motion. The model indicated that earthquakes having a magnitude (Mw) between 5.6 and 7.5 can be possible and the minimal distance to the fault segment can range between 1.7 and 121.1 km in the basin. Five existing dams considered in this study are under near-field motion (Table 2).

The deterministic analyses indicate that peak ground acceleration (PGA) changes within an acceptable range when excluded five dams, which are under the near-field motion. The PGA values range from 0.036g to 0.394g for the 50th percentile and from 0.061g to 0.650g for the 84th percentile, respectively (Table 2). The PGA data are very high for the Yenice-Gonen, Tasoluk, Kirazdere, Gokce and Cokal dams. For Alibey, Buyuk-Cekmece and Sazlıdere dams, the PGA values are also at a considerable level even if they are not under near-field motion.

The probabilistic hazard analyses introduce PGA values within a wide range. For MDE, those are between 0.120g and 0.630g, while the same values range from 0.102g to 0.509g for OBE. The PGA data for OBE and MDE are high for the dams, which are under near-field motion, mentioned above for deterministic analyses. It is an impressive result that maximum PGA values for OBE, MDE, and SEE belong to the Gokce dam even if its energy source produces a moderate magnitude earthquake (5.9 in Mw).The author thinks that it probably depends on earthquake intensity. The probabilistic hazard analyses also give critical values for Cokal, Kirazdere, Tasoluk, and Yenice dams as given in deterministic hazard analyses.

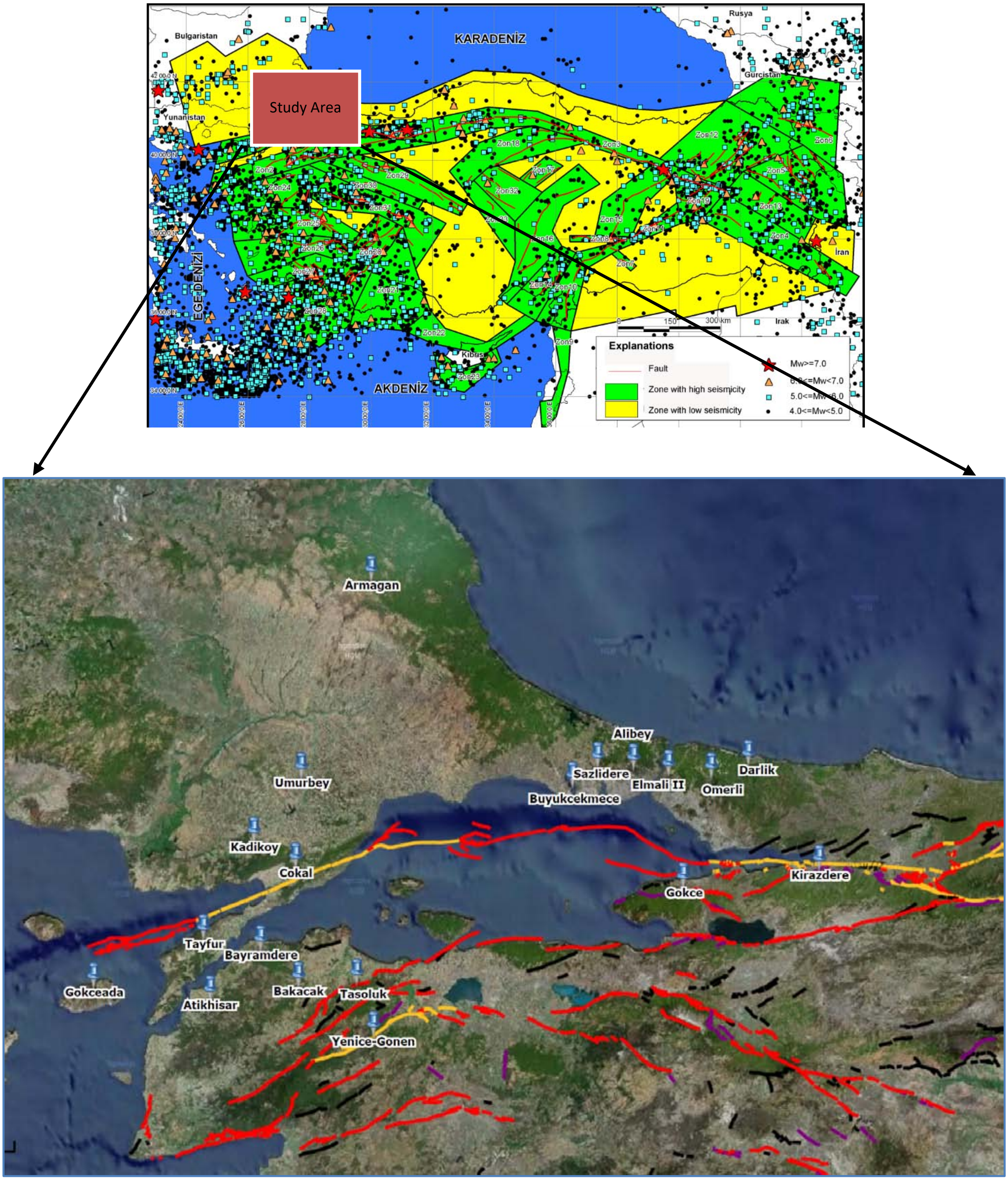

Figure 1: Location of dams on the national seismo-tectonics model and the active fault map (Active faults-yellow color: earthquake surface fracture, red color: Holocene fault, purple color: Quaternary fault, black color: possible Quaternary fault)

Global Journal of Researches in Engineering (E) Volume XX Issue II Version I Year 2020

Table 2: Results of seismic hazard analyses

#	Dam	Deterministic Method *				Probabilistic Method **		
		M_{max}	R_{min}(km)	Mean PGA + 50 (%)	Mean PGA + 84 (%)	OBE in g	MDE in g	SEE in g
1	Alibey	7.5	25.1	0.191	0.313	0.229	0.298	0.413
2	Armagan	6.5	121.1	0.036	0.061	0.102	0.120	0.147
3	Atikhisar	6.5	40.1	0.098	0.163	0.200	0.243	0.300
4	Bakacak	6.6	18.2	0.153	0.255	0.302	0.380	0.492
5	Bayramdere	6.2	26.4	0.091	0.152	0.239	0.293	0.365
6	Buyukçekmece	7.5	14.8	0.281	0.468	0.286	0.393	0.558
7	Cokal	6.3	2.7	0.327	0.540	0.509	0.639	0.825
8	Darlık	7.7	41.2	0.141	0.230	0.146	0.195	0.268
9	Elmali II	7.5	27.3	0.178	0.292	0.210	0.285	0.394
10	Gokce	5.9	3.1	0.285	0.469	0.583	0.709	0.887
11	Gokceada	6.3	21.9	0.101	0.167	0.264	0.324	0.410
12	Kadikoy	6.3	22.5	0.120	0.198	0.276	0.344	0.441
13	Kirazlıdere	6.7	5.3	0.329	0.544	0.433	0.560	0.747
14	Omerli	7.7	34.6	0.164	0.267	0.178	0.238	0.329
15	Sazlidere	7.5	23.0	0.205	0.335	0.225	0.306	0.428
16	Tasoluk	5.6	1.8	0.261	0.429	0.460	0.582	0.761
17	Tayfur	6.3	18.4	0.130	0.216	0.370	0.451	0.565
18	Umurbey	6.7	42.2	0.083	0.138	0.193	0.238	0.299
19	YeniceGonen	6.6	1.77	0.394	0.650	0.391	0.513	0.702

IV. Total Risk Analyses

Throughout this study, the total risk analyses of the basin considered the national specification (DSI, 2012). in which total risk factor depends on reservoir capacity, height, evacuation requirement, and potential hazard, and the Bureau method, which considers dam characteristics, evacuation requirements and downstream damage potential. The national specification adopted the ICOLD (1989) guidelines. The Bureau method recommends four separate risk classes ranging from I (low risk) to IV (extreme risk) as based on the Total Risk Factor (TRF).

Table 3 summaries the total risk analyses of the dams considered in the study. Five dams (Cokal, Gokce, Kirazdere, Tasoluk, and Yenice-Gonen) classified into extremely high hazard ratios with class IV.In comparison, four dams (Alibey, Buyuk-Cekmece, Elmali-II and Sazlidere) have high hazard rating with hazard class of III. Others are identified in classes of I and II (low to moderate hazard rating). The ICOLD (1989) specification classified dams into hazard class IV with hazard rating of extreme, if the PGA value is greater than 0.25g and the energy source is closer than 10 km from the dam site. According to this statement, five dams mentioned above are classified as hazard class IV with a hazard rating of extreme. Throughout study, most dams, classified into hazard classes of III and IV, have a function to provide domestic water for the metropolitan areas.

For nine dams classified into hazard classes of III and IV, the distance from the dam site to active faults, given on updated seismic maps, ranges from 1.7 km to 27.3 km. The large dams of basins, which are under the influence of the near-field motion, have been constructed to very close to the North Anatolian Fault Zone or its offsets passing through from south of the investigation area.

According to DSI Guidelines, all dams with the exception of one structure (Tayfur dam) are categorized into III and IV risk classes with a high and very extremely high-risk rating. Following the Bureau's method, five large dams are classified in risk class III, high-risk rating, while others are in the moderate risk ratio with class of II. The total risk analyses indicate that the solutions obtained from the Bureau method are more rational than those estimated by the DSI guidelines.

Table 3: The total risk of dams considered for this study

#	Dam	Hazard Analysis		Total Risk (ICOLD,1989)			Total Risk (Bureau, 2003)		
		Class	Hazard Ratio	Risk factor	Risk class	Risk ratio	Risk factor	Risk class	Risk ratio
1	Alibey	III	High	30	III	High	223.30	III	High
2	Armagan	I	Low	30	III	High	99.28	II	Moderate
3	Atikhisar	I	Low	24	III	High	143.97	III	High
4	Bakacak	II	Moderate	36	IV	Very high	137.55	III	High
5	Bayramdere	I	Low	26	III	High	83.98	II	Moderate
6	Buyukçekmece	III	High	22	III	High	150.80	III	High
7	Cokal	IV	Extreme	36	IV	Very high	141.14	III	High
8	Darlık	II	Moderate	32	IV	Very high	160.30	III	High
9	Elmali II	III	High	32	IV	Very high	180.20	III	High
10	Gokce	IV	Extreme	34	IV	Very high	124.55	II	Moderate
11	Gokceada	II	Moderate	24	III	High	136.27	III	High
12	Kadikoy	II	Moderate	24	III	High	143.35	III	High
13	Kirazdere	IV	Extreme	34	IV	Very high	146.09	III	High
14	Omerli	II	Moderate	36	IV	Very high	217.0	III	High
15	Sazlidere	III	High	32	IV	Very high	158.40	III	High
16	Tasoluk	IV	Extreme	34	IV	Very high	116.85	II	Moderate
17	Tayfur	II	Moderate	16	II	Moderate	67.10	II	Moderate
18	Umurbey	I	Low	26	III	High	134.82	III	High
19	YeniceGonen	IV	Extreme	36	IV	Very high	214.06	III	High

The TRF values range from 67.10 to 223.3 according to the Bureau method. There are five dams of a risk class of II and fourteen dams of a risk class of III, while there is no dam having a risk class of I in the basin. In other words, seventy-four percent of total dams are identified as a risk class of III with high risk ratio, while the rest are being in class of II with moderate risk ratio.

V. Discussions

There are so many small and large dams in the Marmara basin, Turkey. Some of them, namely Alibey, Buyuk-Cekmece, Cokal, Elmali-II, Gokce, Kirazdere, Sazlidere, Tasoluk, and Yenice-Gonen, has mainly been built for providing domestic water and located in the metropolitan area. These dams have been discussed in more detail in the papers submitted in the local symposiums held in Turkey (Tosun and Onder, 2018 and Tosun, 2019b). The dams, categorized into hazard class of III and IV with high to extremely high hazard ratio and into the total risk of III with high-risk ratio, can cause very serious conditions for downstream life and property when they fail. The author evaluates their earthquake safety and total risk in more detail as given below.

Alibey Dam, located on Alibey river in the Marmara basin, is an embankment dam 28.0-m high with a total embankment volume of 1 927 000 m3. The facility will impound 65.0 hm3 of water with a reservoir surface area of 4.75 km2 at the maximum water level. It provides domestic water with an annual capacity of 33.0 hm3. The side slopes of the main embankment are 2.0H:1V for both upstream and downstream (H=horizontal and V=vertical)). In the section, there are a central impervious zone, which is composed of impervious clay, and a transition section of granular materials to protect the central impervious clay. The shell fill in downstream and upstream parts is composed of semi-pervious clayey material. The geotechnical engineers designed vertical sand drains to provide quick-consolidation of the clayey layer of soft alluvium on the river bed. The analyses indicate that this dam is one of the more critical structure within the Istanbul Metropolitan Area. According to DSHA, the peak ground acceleration resulted by an earthquake of 7.5 magnitudes is 0.191g. As based on PSHA, the values of peak ground acceleration for OBE and MDE are 0.229g and 0.298g, respectively. It is 25.1 km far away from an active fault given in the new seismo-tectonic map of Turkey adopted in 2013.The dam, identified a risk class of III, hasa TRF value of 223.3. The 37-years old embankment is in excellent condition. However, the author recommends its seismic upgrade soon.

Buyuk-Cekmece dam is an earthfill dam located in the Istanbul Metropolitan Area. It has only a 10.1 m height from the river bed, however, its total storage capacity is relatively high. When the reservoir is at maximum capacity, the facility impounds 172.5 hm3 of water with a reservoir surface area of 28.58 km2. It provides domestic water with an annual capacity of 82 hm3 for the European part of the Istanbul metropolitan area. The crest length is 2 476 m, and the side slopes of main embankment are3.0H:1V for both upstream and downstream side (H=horizontal and V=vertical). In the section, there are a central impervious core, which is composed of compacted impervious clay, and a transition section of sandy and gravelly aggregates between the core clay and semi-pervious soils. The alluvium on the river bed, which is composed of different sizes of river bed material, was removed before beginning the construction of the main embankment of dam. According to the DSHA, the peak ground acceleration by an earthquake of 7.5 magnitudes is 0.281g. The PSHA indicates that the values of peak ground acceleration for OBE and MDE are 0.286g and 0.393g, respectively. The dam embankment is only 14.8 km far away from an active fault given in the new seismo-tectonic map of Turkey adopted for 2013.The dam, identified as a risk class of III, has a TRF value of150.8. This 31-year old earthfill dam is in excellent condition, but it cannot meet current seismic design standards. Additionally, it is relatively close to the energy source.

Cokal dam, located at the European part of the Marmara basin, was designed as the type of concrete faced rockfill dam (CFRD). It impounds 204.0 hm3 of water at maximum water level and has 81 m height from the foundation and 571 m length on the crest. The dam body is mainly composed of rockfill material. There is a transition section between the face concrete lining and rockfill. The side slopes are 1.4H: 1V for upstream and downstream of dam body (Fig.2). The impervious section consists of the concrete slab and the plinth structure on the downstream face. The alluvium on the river bed, which is composed of sandy and gravelly clay, was removed before commencing the construction of the dam body. According to the DSHA, the peak ground acceleration resulted by an earthquake of 6.3 magnitudes is 0.327g as based on PSHA, the values of peak ground acceleration for OBE and MDE are 0.509g and 0.639g, respectively. The dam is only 2.7 km far away from the main faulting system, which has a surface rupture of the North-Anatolian Faulting System in the west. The dam, identified as a risk class of III, has a TRF value of 141.1. Intensive investigations showed that the behavior of CFRD's is questionable after the Wenchuan earthquake of 12 May 2008 in China (Tosun, 2015). Cokal dam is one of most critical structures of the Marmara basin. Therefore, it should be re-analyzed using sophisticated programs to describe its dynamic behavior under severe excitation conditions even if it is a young dam.

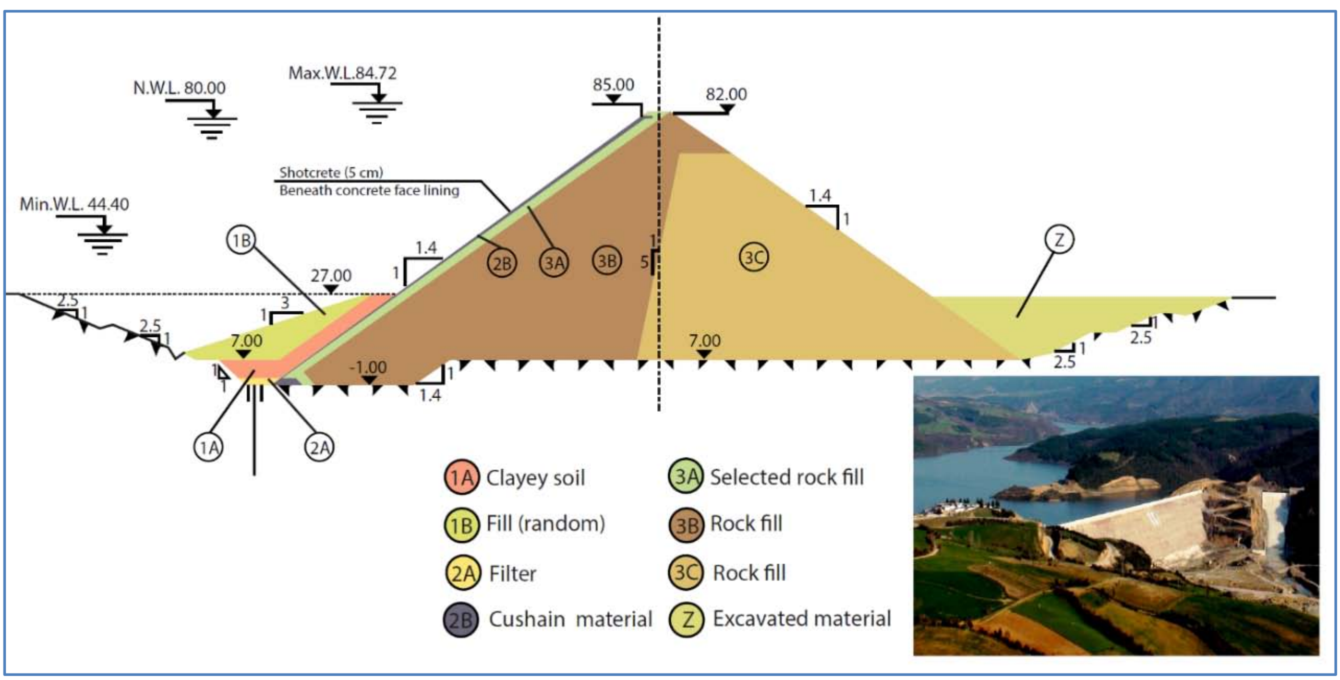

Figure 2: Maximum cross-section of Cokal dam

The Elmali-II dam is a unique rigid-typed structure of the basin with a volume of 0.10 hm3 of concrete gravity body. The dam, located on the Goksu river in the Anatolian part of Istanbul Metropolitan Area, has 65-years old. Its height from river bed is 42.5 m. At the maximum water level, the facility will impound 10.31 hm3 of water with a reservoir surface area of 42 km2. Its function is to provide domestic water for Istanbul city. The seismic hazard analyses indicate that this dam is one of safe structures within the Marmara basin. The peak ground acceleration produced by an earthquake of 7.5 magnitudes is 0.178g, and it is 27.3 km far away from an active fault. The PSHA indicates that the values of peak ground acceleration for OBE and MDE are 0.210g and 0.285g, respectively. Its TRF value is 180.2, and it has a risk class of III. The Elmali-II dam, which is the oldest one of the dams considered for this study is in excellent condition. However, it is necessary to have a seismic upgrade for the dam soon.

Gokce dam is an earth-rockfill typed with a total embankment volume of 133 000 m3.The 50-m high dam, located on the Gokce river in Marmara basin, has a function for providing domestic water of Yalova city and its vicinity. The facility approximately will impound 21.71 hm3 of water with a reservoir surface area of 1.3 km2 at the maximum water level. The crest width is 10 m, and the side slopes of main embankment are 3.0H:1V for upstream and 2.0H: 1V for downstream (H=horizontal and V=vertical). In the section, there are a central impervious core, which is composed of compacted clay, and a transition section of sand, gravel and small-sized crushed rock between the core and rockfill materials for the downstream part and a natural filter zone between the core and earthfill material for the upstream. The downstream shells consist of large-sized crushed rocks. The DSHA and PSHA indicate that Gokcedam is one of the most critical dams within the basin. The DSHA indicates that the peak ground acceleration produced an earthquake of 5.9 magnitudes is 0.285g, and its embankment is 3.1 km far away from a secondary active fault given in the updated seismo-tectonic map of Turkey. According to PSHA, the values of peak ground acceleration for OBE and MDE are 0.583g and 0.709g, respectively. Its TRF value is 124.6, and the 31-years old dam has a risk class of III with high risk ratio.

Kirazdere dam is a rockfill dam on the Kirazdere River within the Kocaeli Metropolitan area. It has a 109.0 m height from river bed. When the reservoir is at maximum capacity, the facility impounds 60.0 hm3 of water in its reservoir. The dam, finished in 1999, has a function to provide domestic water with an annual capacity of 142 hm3. According to the deterministic seismic hazard analyses, the peak ground acceleration produced by an earthquake of 6.7 magnitudes is 0.329g. Its embankment is 5.3 km far away from the main segment of the North Anatolian Fault Zone given in the updated seismo-tectonic map of Turkey. According to PSHA, the values of peak ground acceleration for OBE and MDE are 0.433g and 0.560g, respectively. The Kocaeli Municipality operates it. This 21-year old rockfill embankment is in excellent condition, but it cannot meet current seismic design standards. It will be under near-field motion during a forthcoming earthquake. Its TRF value is 146.1, and it has a risk class of III with high risk ratio. Its risk increases because of being no alternative water resources in the region.

Sazlıdere dam is a rockfill dam on the Sazlıdere River near Arnavutköy County. It has a 23.0 m height from river bed. When the reservoir is at maximum capacity, the facility impounds 131.50 hm3 of water with a reservoir surface area of 11.77 km2. The dam, finished in 1996, has a function to provide domestic water for the İstanbul city with an annual capacity of 55.0 hm3. The crest length is 435 m, and the side slopes of the main embankment are 2.25H:1V for upstream and 2.0H: 1V for downstream (H=horizontal and V=vertical). In the section, there are a central impervious core, which is composed of compacted impervious clay, and a transition section of sandy and gravelly aggregates between the core and finely crushed rockfill. According to the DSHA of this study, the peak ground acceleration produced by an earthquake of 7.5 magnitudes is 0.205 g, and its embankment is 23.0 km far away from an active fault given in the updated seismo-tectonic map of Turkey. The PSHA indicates that the values of peak ground acceleration for OBE and MDE are 0.225g and 0.306g, respectively. Its TRF value is 158.4, and it has a risk class of III. This 24-year old rockfill embankment is in excellent condition. Its reservoir is under the influence of the Istanbul Canal Project to be realized in forthcoming years.

The Tasoluk dam, constructed as rockfill type with embankment volume of 1.7 hm3 on the Tasoluk River of the Marmara Basin in Canakkale province, has a 65-m height from the river basin. The facility impounds 79.4 hm3 of water when the reservoir is at maximum capacity. The dam, finished in 2009, has a function to provide irrigation water. The side slopes of main embankment are 2.0H:1V for upstream and downstream (H=horizontal and V=vertical). In the section, there is a central impervious core, which is composed of compacted clay, and a transition section of granular material between the core and fine crush rock zone materials for both sides (Fig. 3). According to the seismic hazard analyses of this study, Tasolukdam is one of the most critical structures of Marmara basin that the peak ground acceleration by an earthquake of 5.6 magnitude using the DSHA is 0.261g. The PSHA indicates that the values of peak ground acceleration for OBE and MDE are 0.460g and 0.582g, respectively. Its TRF value is 116.9, and it has a risk class of III. Dam site is 1.8 km far away from an active fault.

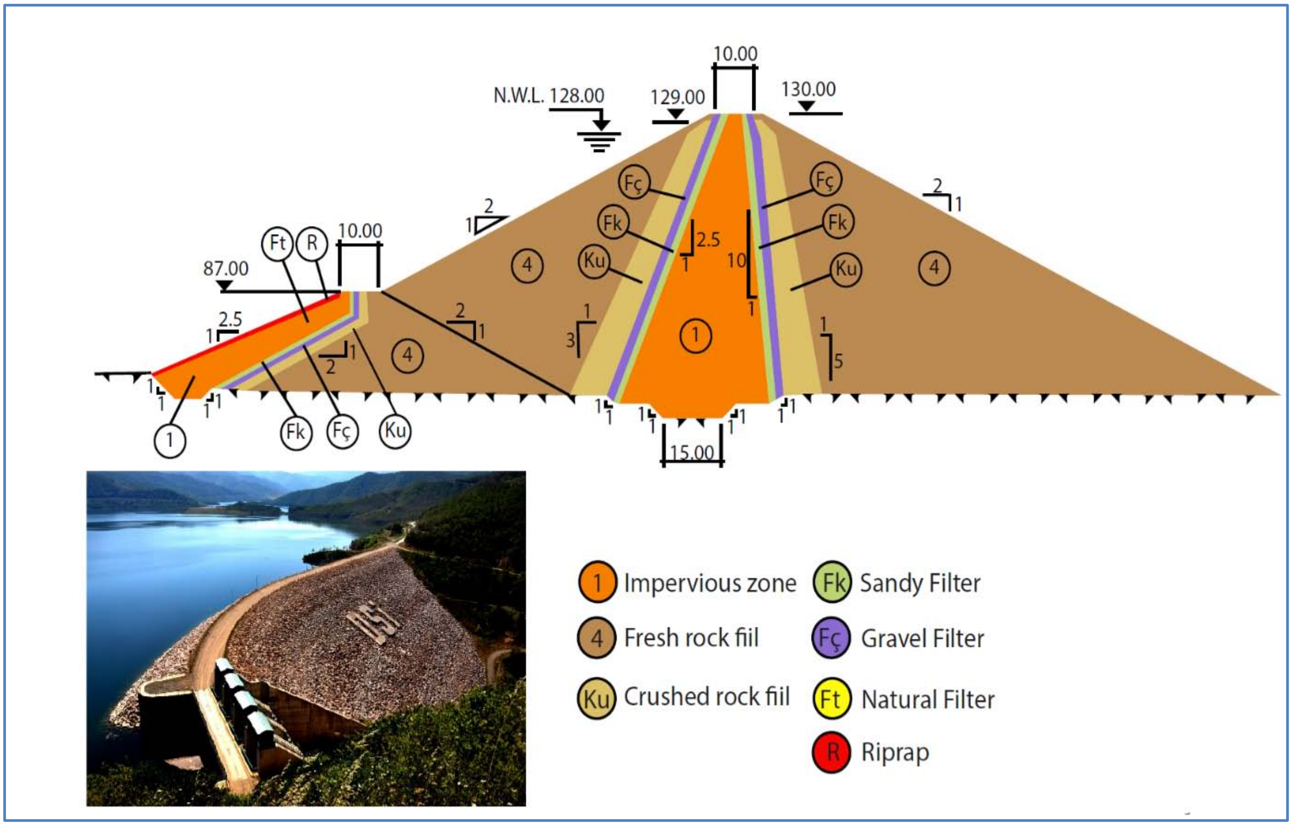

Figure 3: Geometry of Tasoluk dam

The Yenice-Gonen dam is a zoned earth-rockfill dam on the Gonen River near Yenice County, located in the southern portion of the basin. It has a 78-m height from the foundation. It has a reservoir volume of 227 hm3 with a surface area of 15.4 km2. Its crest length is 293 m. Its embankment construction was started in 1993 and completed in 1997. It was designed a multi-purpose structure for irrigating lands, producing electricity, supplying domestic water, and providing flood control. It is an earth-rockfill dam with a central core. The slopes are 3.0H:1V for both sides (H=horizontal and V=vertical). The shell is composed of earth and rockfill materials for upstream and downstream, respectively. There is a transition section of sand, gravel, and small-sized crushed rock between the core and shell materials (Fig. 4).The alluvium on the river bed, which is composed of sand, gravel and fine mixtures, was removed before beginning the construction of the main embankment of the dam. The dam axis is very close to the Yenice-Gonen Fault Zone (YGFZ), which extends from Gonen East in the Northeast to Yenice's Southwest in the southwest. This fault zone caused an earthquake on March 18, 1953, with a magnitude of 7.2. It is only 1.71 km far away from the surface collapse of YGFZ. The seismic hazard analyses indicate that it is one of the critical dams within the basin. The peak ground acceleration produced by an earthquake of 6.6 magnitudes is 0.394 g. It is only1.77 km far away from the active fault. Moreover, its risk is high for downstream life (total risk factor is 214.1 with high-risk ratio).

Global Journal of Researches in Engineering (E) Volume XX Issue II Version I Year 2020

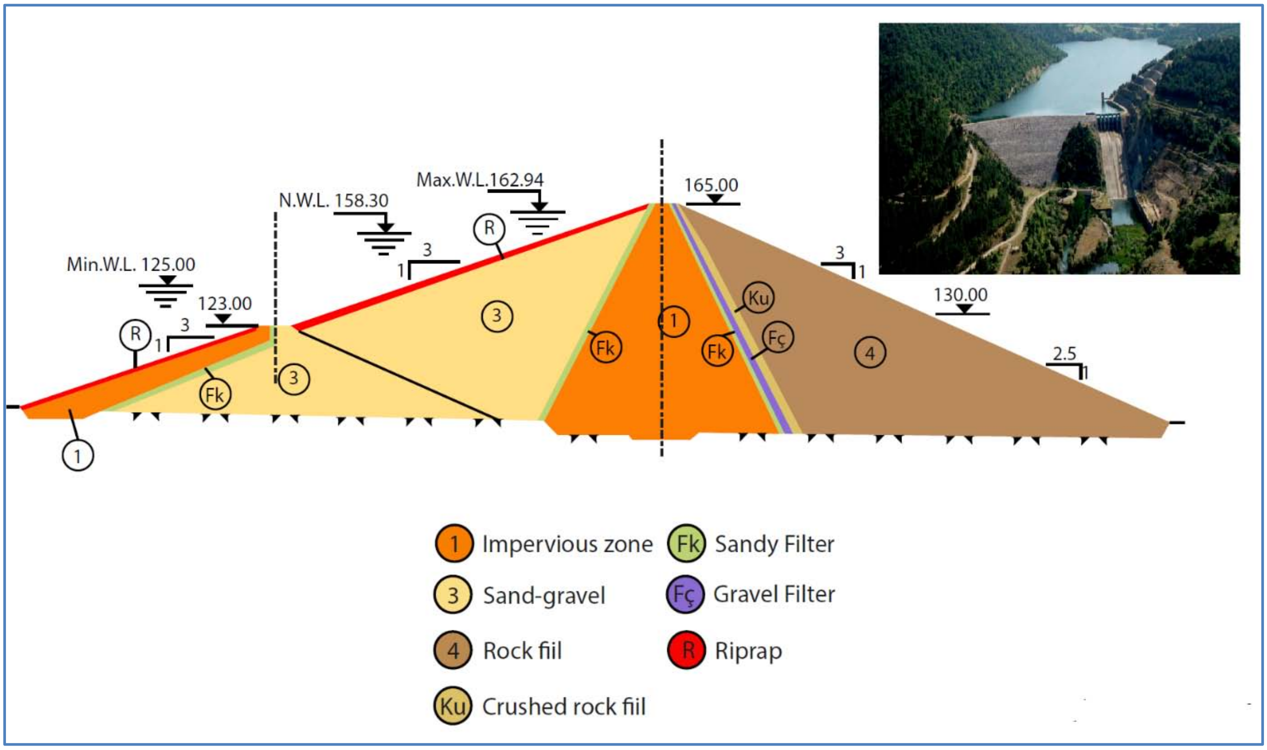

Figure 4: Maximum cross-section of Yenice-Gonen dam

VI. Conclusions

For this study, nineteen large dams, located on different seismic zones of the Marmara basin, were analyzed to estimate their seismic hazards and risk classes based on the actual earthquakes occurred within the basin and structural features of dams. The North Anatolian Fault zones and its secondary segments are the most critical zone for the basin. There are five existing dams under the near-field motion when considered the new seismo-tectonic map of Turkey. The analyses indicate that Cokal, Gokce, Kirazdere, Tasoluk, and Yenice-Gonen dams are the most critical dams of the basin. Additionally, four large dams (Alibey, Buyuk-Cekmece, Elmali-II, and Sazlıdere), possessing the hazard class of III with high hazard ratio, are also critical dams in the Marmara basin. As a result of this study, 47.4 percent of the dams have been identified as the structures in high and extremely high hazard ratios. In comparison, 31.5 percent of dams is in a moderate hazard ratio. The rest are relatively safe structures when we consider public safety. The author points out that local predictive relationships are an appropriate methodology for estimating the seismic parameters to be used in dynamic analyses. The study clarifies another fact that probabilistic seismic hazard analysis introduces relatively higher PGA values for the dams having high earthquake intensity. Development of attenuation relationships between PGA values obtained from probabilistic and deterministic seismic hazard analyses as considering earthquake intensity can be an promising area for forthcoming studies.

References Références Referencias

1. Ambraseys, NN.1995. The Prediction of Earthquake Peak Ground Acceleration in Europe. Earthquake Engineering and Structural Dynamics, V.24, 467-490.
2. Ambraseys, NN., Douglas, J, Karma, SK and Smit, PM. 2005. Equations for the Estimation of Strong Ground Motions from Shallow Crustal Earthquakes Using Data from Europe and the Middle East. Horizontal Peak Ground Acceleration and Spectral Acceleration, Bulletin of Earthquake Engineering, 3, 1-53.
3. Boore, DM, Joyner, WB. and Fumal, TE. 1993. Estimation of response spectra and peak accelerations from Western North American earthquakes. An interim report. Open file report 93-509.U.S.G.S.
4. Boore, DM., Joyner, WB. and Fumal, TE. 1997. Equation for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes. A Summary of recent Work. Seismological Research Letters, V.68, N.1, January /February, 128-153.
5. Bureau, GJ. 2003. Dams and Appurtenant Facilities in Earthquake Engineering Handbook edited by Chenh, W.F and Scawthorn,C. CRS press, Bora Raton 26.1-26.47.
6. Campbell, KW. 1981. Near-Source Attenuation of Peak Horizontal Acceleration: Bulletin Seism. Soc. Am., V.71, N.6, 2039-2070.

7. Campbell, KW. and Bozorgnia, Y. 1994. Near-source attenuation of peak horizontal acceleration from worldwide accelerograms recorded from 1957 to 1993: Proceeding of the Fifth U.S. National Conference on Earthquake Engineering. V.3, 283-292.
8. DSI. 2012. Selection of Seismic Parameters for Dam Design. State Hydraulic Works, Ankara, 29 p (in Turkish).
9. DSI .2016. Dams of Turkey. TR-COLD, Ankara, 602 p.
10. FEMA. 2005. Federal Guidelines for Dam Safety—Earthquake Analyses and Design of Dams.
11. Fraser, WA and Howard, JK. 2002. Guidelines for Use of the Consequence-Hazard matrix and Selection of Ground Motion Parameters: Technical Publication, Department of Water Resources, Division of Safety of Dams.
12. Gulkan, P and Kalkan, E. 2002. Attenuation modeling of recent earthquakes in Turkey. Journal of Seismology, 6(3), 397-409.
13. Hariri-Ardebili, Mohammad A. Salamon, Jerzy; Mazza, Guido; Tosun, Hasan; Xu, Bin. 2020. Advances in Dam Engineering. Infrastructures 5, no. 5: 39.
14. ICOLD. 1989. Selecting Parameters for Large Dams-Guidelines and Recommendations. ICOLD Committee on Seismic Aspects of Large Dams, Bulletin 72.
15. ICOLD. 2016. Selecting Seismic Parameters for Large Dams-Guidelines. ICOLD, Bulletin 148.
16. Jiminez, MJ, Giardini, D and Grünthal, G. 2001. Unified Seismic Hazard Modelling throughout the Mediterranean Region. Bolettino di Geofisica Teoricaed Applicata, Vol.42, N.1-2, Mar-Jun., 3-18.
17. Kalkan, E veGulkan, P. 2004. Site-Dependent Spectra Derived from Ground Motion Records in Turkey, Earthquake Spectra, 20, 4, 1111-1138.
18. Kramer, SL. 1996. Geotechnical Earthquake Engineering: Prentice-Hall, Upper Saddle River, NJ 653 p.
19. Krinitzsky, E. 2005. Discussion on Problems in the Application of the SSHAC Probability Method for Assessing Earthquake Hazards at Swiss nuclear power plants. Eng. Geol. 78 285-307; Eng.Geo. 82, 62-68.
20. MTA. 2013. Scale 1/1.125.000 Turkey Live Fault Map. General Directorate of Mineral Research and Exploration. Special publications series, Ankara, Turkey.
21. Seyrek,E. and Tosun, H. 2011. Deterministic approach to the seismic hazard of dam sites in Kızılırmak basin, Turkey. Natural hazards, 59 (2), 787.
22. Seyrek, E and Tosun, H. 2013. Influence of analysis methods for seismic hazard on total risk of large concrete dams in Turkey. GaziUniv, J. Fac Engineering Architecture, 28-1, 67-75.
23. Tosun, H. 2002. Earthquake-Resistant Design for Embankment Dams: Publication of General Directorate of State Hydraulic Works, Ankara. 208 pp. (in Turkish).
24. Tosun, H. and Savas, H. 2005. Seismic hazard analyses of concrete dams in Turkey. in Proceeding of CDA Annual Conference.
25. Tosun, H. 2006. Seismic studies. International Water Power & Dam Construction, 58 (2), 20-23.
26. Tosun, H. 2007. Total Risk Analysis of Damand Appurtenant Structures in a Basin and a Case Study. International Congress in River Basin Management, Volumel, 22-24 March, Antalya, 477-488.
27. Tosun, H. and Turkoz, M. 2007. Total risk-analyzing methods for dam structures and a case study in Turkey. in Proceeding of CDA Annual Conference.
28. Tosun, H., Zorluer, I. Orhan, A. Seyrek, E. Savaş, H. and Türköz, M. 2007a. Seismic hazard and total risk analyses for large dams in Euphrates basin, Turkey. Engineering Geology 89 (1-2), 155-170,
29. Tosun, H.Türkoz, H. and Savas, H. 2007b. River basin risk analysis. Int. Water Power and Dam Construction, May issue.
30. Tosun, H.Turkoz, M. Savas, H. and Seyrek, E. 2007c. River basin risk analysis.International Water Power and Dam Construction, 59 (5), 30.
31. Tosun, H. 2008. Evaluating Earthquake Safety for Large Dams in Southeast Turkey. Hydro Review Worldwide (HRW), 34-40.
32. Tosun, H. and Seyrek,E. 2010.Total risk analyses for large dams in Kizilirmak basin, Turkey. Natural Hazards and Earth System Sciences, 10 (5), 979.
33. Tosun,H. 2011. Re-analysis of Ataturk Dam under Ground Shaking by Finite Element Models. In Proceeding of CDA Annual Conference, September 22-27. Saskatoon, Canada.
34. Tosun, H. 2012. Earthquake Safety of Keban Dam, Turkey. in Proceeding of CDA Annual Conference, October 15-20. Fredericton, NB, Canada, 2012.
35. Tosun, H. 2015. Earthquakes and dams. in charter of Earthquake Engineering (edited by A. Moustafa), Chapter 7, Intechopen, 189-198. (http://dx.doi.org/10.5772/59372).
36. Tosun, H and Oguz, S. 2017. Stability Analysis of Atatürk dam, Turkey as Based on the Updated Seismic Data and Design Code. in Proceeding of 85th Annual Meeting of International Commission on Large Dams, Prague, 66-66.
37. Tosun, H and Tosun, V.T. 2017a. Total risk and seismic hazard analyses of large dams in northwest Anatolia, Turkey. ICOLD 85th Annual Meeting, July 3-7, Prague.
38. Tosun, H. and Tosun, V.T. 2017b. Dynamic Analysis of Embankment Dams Under Strong Seismic

Excitation and a Case Study", in Proceeding of Long-Term Behaviour and Environmentally Friendly Rehabilitation Technologies of Dams (LTBD 2017), Tehran, (DOI:10.3217/978-3-85125-564-5-102)

39. Tosun, H. 2018. Safety Assessment of Large Reservoir Constructed for Domestic Water Near Urban Areas and a Case Study. in Proceeding of ICOLD-ATCOLD Symposium on Hydro Engineering, Wien, 917-927.
40. Tosun, H. and Onder, T.B. 2018. Safety assessment for existing large reservoirs constructed in Istanbul metropolitan area. in Proceeding of 5th International Symposium on Dam Safety. October 27-31. Istanbul.
41. Tosun,H, Tosun,V.T and Hariri-Ardebili, M.A. 2020. Total risk and seismic hazard analysis of large embankment dams: case study of Northwest Anatolia, Turkey. Life Cycle Reliability and Safety Engineering, 1-10, (https://doi.org/10.1007/s41872-020-00113-4).
42. Tosun, H. 2019a. Dam Engineering (edited by H.Tosun). Intech Open, (DOI: 10.5772/intechopen.74153).
43. Tosun, H. 2019b. Earthquake Safety Evaluation for Large Dams in Marmara Basin, Turkey. VI. in Proceeding of International Earthquake Symposium, September 25-27. Kocaeli. Turkey
44. Tosun, H and Seyrek, E. 2012. Selection of the appropriate methodology for earthquake safety assessment of dam structures. In chapter Advances in Geotechnical Earthquake Engineering (edited by A. Moustafa). Intechopen. 167-188 (DOI: 10.5772/29721).

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Geometrical Characteristics of the Surfaces on Trapezium-Curved Plans

By Dr. V N Ivanov & Imomnazarov T.S
Friendship University of Russia

Abstract- At the article “Orthogonal curved coordinate system and forming the surfaces on trapezium plans” [1] there is given the method of forming of the orthogonal curved coordinate system at the plane and the methodic of forming of the new forms of the surfaces on the given trapezium curved plans. At the article there are given many pictures of the trapezium curved plans on the base of the different directrix curves and the figures of the surfaces on the given trapezium curved plans and the combinations of the surfaces with conjugated different directrix. The given methodic of the forming of the surfaces may be used in architecture and building for development of thin-walled space constructions in urban and industry building. But for calculation of stress-strain state of thin shell usually there are used the geometrical characteristics of the middle surface of the shell. At this state on the base of the vector equation of the surfaces on the trapezium curved plans there are received the formulas of the coefficients of the fundamental forms and of the curvatures of the surfaces. There are given the examples of the surfaces and there are received the formulas of the coefficients of the fundamental forms and curvatures of the surfaces with concrete directrix and functions of vertical coordinates of the surface.

Keywords: plane curve, orthogonal curved coordinate system at the plane, trapezium-curved plan, vector equation of the surface at the trapezium curved plans, geometrical coefficients of the fundamental forms of the surface, curvatures of the surface.

GJRE-E Classification: FOR Code: 120199, 290899

GEOMETRICALCHARACTERISTICSOFTHESURFACESONTRAPEZIUMCURVEDPLANS

Strictly as per the compliance and regulations of:

Geometrical Characteristics of the Surfaces on Trapezium-Curved Plans

Dr. V N Ivanov [α] & Imomnazarov T.S [σ]

Abstract- At the article “Orthogonal curved coordinate system and forming the surfaces on trapezium plans” [1] there is given the method of forming of the orthogonal curved coordinate system at the plane and the methodic of forming of the new forms of the surfaces on the given trapezium curved plans. At the article there are given many pictures of the trapezium curved plans on the base of the different directrix curves and the figures of the surfaces on the given trapezium curved plans and the combinations of the surfaces with conjugated different directrix. The given methodic of the forming of the surfaces may be used in architecture and building for development of thin-walled space constructions in urban and industry building. But for calculation of stress-strain state of thin shell usually there are used the geometrical characteristics of the middle surface of the shell. At this state on the base of the vector equation of the surfaces on the trapezium curved plans there are received the formulas of the coefficients of the fundamental forms and of the curvatures of the surfaces. There are given the examples of the surfaces and there are received the formulas of the coefficients of the fundamental forms and curvatures of the surfaces with concrete directrix and functions of vertical coordinates of the surface.

Keywords: plane curve, orthogonal curved coordinate system at the plane, trapezium-curved plan, vector equation of the surface at the trapezium curved plans, geometrical coefficients of the fundamental forms of the surface, curvatures of the surface.

I. Introduction

Equation of the surface on the trapezium-curved plan, coefficients of quadratic forms of the surface.

The orthogonal curved system of coordinates at the plane there is formed by the system of the straight lines orthogonal to the plane base curve $\boldsymbol{r}_0(u)=x(u)\boldsymbol{i}+y(u)\boldsymbol{j}$ (Fig. 1).

So, the curved-orthogonal coordinates there are organized by the system of the equidistant curves parallel to the based curve and the system of the straight lines orthogonal to the system of the equidistant curves.

The equation of the curved coordinate system

$$\boldsymbol{r}(u,v)=\boldsymbol{r}_0(u)-v\boldsymbol{\nu}\ , \tag{1}$$

$\boldsymbol{\nu}$ is a normal to the base curve, v is the coordinate of the generating curves along the normal to the base curve.

The positive direction of the coordinate of straight lines there is taken to the side of the convexity of the base curve, because in the direction of the concavity the straight lines may to cross.

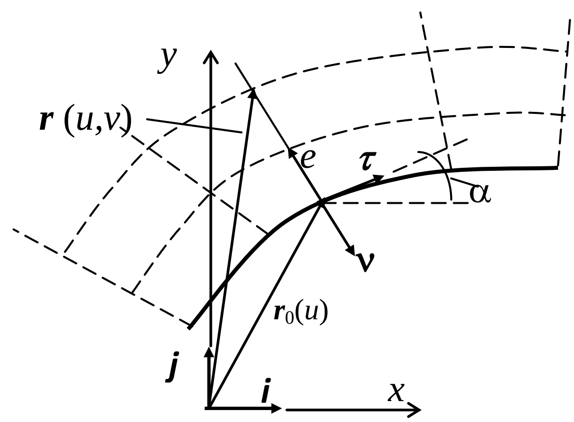

Fig. 1: Pseudo-polar coordinate system

Assigning some function of vertical coordinate *z(u,v)*, we receive the vector equation of the surface $\boldsymbol{\rho}(u,v)$ on the base curved-orthogonal coordinate system at the plane

$$\boldsymbol{\rho}(u,v)=\boldsymbol{r}_0(u)-v\boldsymbol{\nu}+z(u,v)\boldsymbol{k}\ . \tag{2}$$

For deduction the formulas of the coefficients it’s necessary to receive the derivatives of the vector equation and to use the formulas of the classic differential geometry [2];

$$\boldsymbol{r}_0'=s'\boldsymbol{\tau}\ ;\ \ s'=\left|\boldsymbol{r}_0'\right|;\ \ \ \boldsymbol{\tau}'=s'k\boldsymbol{\nu}=k_s\boldsymbol{\nu}\ ;\ \ k_s=s'k\ ;\ \ \boldsymbol{\nu}'=-k_s\boldsymbol{\tau}\ . \tag{3}$$

Then receive:

$$\boldsymbol{\rho}_u=\left(s'+vk_s\right)\boldsymbol{\tau}+z_u\boldsymbol{k}\ ;\qquad \boldsymbol{\rho}_v=-\boldsymbol{\nu}+z_v\boldsymbol{k}\ . \tag{4}$$

Author α σ: Department of Architecture and Civil engineering, Engineering Academy Peoples’ Friendship University of Russia, Miclukho-Maklaya str., 6, Russia, 117198. e-mails: i.v.ivn@mail.ru, timur-imomnazarov@mail.ru

The coefficients of the first fundamental forms:

$$E=(\boldsymbol{\rho}_u\boldsymbol{\rho}_u)=(s'+vk_s)^2+z_u^2;\quad G=(\boldsymbol{\rho}_v\boldsymbol{\rho}_v)=1+z_v^2;\quad F=(\boldsymbol{\rho}_v\boldsymbol{\rho}_v)=z_u z_v. \tag{5}$$

The unit normal vector of the surface

$$\boldsymbol{m}=\frac{1}{\Sigma}(\boldsymbol{\rho}_z\times\boldsymbol{\rho}_v)=\frac{1}{\Sigma}(z_u\boldsymbol{\tau}-(s'+vk_s)(z_v\boldsymbol{\nu}+\boldsymbol{k})), \tag{6}$$

$\Sigma=\sqrt{EG-F^2}=|(\boldsymbol{\rho}_z\times\boldsymbol{\rho}_v)|=\sqrt{(s'+vk_s)^2(1+z_v^2)+z_u^2}$ is a discriminant of the surface.

The second derivatives of the equation:

$$\boldsymbol{\rho}_{uu}=(s''+vk_s')\boldsymbol{\tau}+(s'+vk_s)k_s\boldsymbol{\nu}+z_{uu}\boldsymbol{k};\quad \boldsymbol{\rho}_{uv}=k_s\boldsymbol{\tau}+z_{uv}\boldsymbol{k};\quad \boldsymbol{\rho}_{vv}=z_{vv}\boldsymbol{k}. \tag{7}$$

The coefficients of the second fundamental form:

$$L=(\boldsymbol{\rho}_{uu}\boldsymbol{m})=\frac{(s''+vk_s')z_u+(s'+vk_s)^2k_s z_v-(s'+vk_s)z_{uu}}{\Sigma};$$

$$N=(\boldsymbol{\rho}_{vv}\boldsymbol{m})=\frac{(s'+vk_s)z_{vv}}{\Sigma};\quad M=(\boldsymbol{\rho}_{uv}\boldsymbol{m})=\frac{-z_u k_s-(s'+vk_s)z_{uv}}{\Sigma}. \tag{8}$$

The curvatures of the surface:

$$k_u=\frac{L}{E}=\frac{(s''+vk_s')z_u+(s'+vk_s)^2k_s z_v-(s'+vk_s)z_{uu}}{\Sigma\left[(s'+vk_s)^2+z_u^2\right]};$$

$$k_v=\frac{N}{G}=\frac{(s'+vk_s)z_{vv}}{\Sigma(1+z_v^2)};\quad k_{uv}=\frac{M}{\sqrt{EG}}=\frac{-z_u k_s-(s'+vk_s)z_{vv}}{\Sigma\left[(s'+vk_s)^2+z_u^2\right]\sqrt{(1+z_v^2)}}. \tag{9}$$

The coordinate system of the investigated surfaces isn't orthogonal and isn't conjugated in common, as the coefficients $F, M\neq 0$ and the coordinate system of the surfaces isn't the lines of principle curvatures of the surface.

The investigated system of the surfaces is related to the class of normal surfaces [4-6] – the surfaces with the system of plane coordinate lines (generating curves) at the normal plane of the directrix curve. At the works [4, 5] there was shown, that only for two kinds of normal surfaces the system of generating curves is the system of principle curvatures: 1- surfaces of rotation – directrix is a straight line, generating lines are circles; 2 – normal surfaces with the system of non-changed generating curve. This type of surfaces is related to the Monge's surfaces [5, 7-10].

If $z=z(v)$ – the generating curve doesn't change during moving in normal plane of the directrix ($z_u=z_{uu}=0$), there will be received the Monge's surfaces:

$$E=(s'+vk_s)^2;\quad G=(\boldsymbol{\rho}_v\boldsymbol{\rho}_v)=1+z_v^2;\quad F=0;\quad \Sigma=(s'+vk_s)\sqrt{1+z_v^2};$$

$$L=\frac{(s'+vk_s)k_s z_v}{\sqrt{1+z_v^2}};\quad N=\frac{z_{vv}}{\sqrt{1+z_v^2}};\quad M=0;$$

$$k_1==\frac{k_s z_v}{(s'+vk_s)\sqrt{1+z_v^2}};\quad k_2=\frac{z_{vv}}{(1+z_v^2)^{3/2}}. \tag{10}$$

The coordinate system of the Monge's surfaces is lines of principle curvatures of the surface.

If the generating curve will be a straight line $z=vtg\theta$ (θ is an angle of slope of generating strait line to the plane of base curve), then there will be received the torus surface of constant slope [10-12]. Then we'll receive:

$$z_v = tg\theta\,;\;\; z_{vv} = 0\,;\;\; 1 + z_v^2 = \frac{1}{cos^2\theta}\,;\;\; \Sigma = \frac{s' + vk_s}{cos\theta}\,;$$

$$E = (s' + vk_s)^2\,;\;\; G = \frac{1}{cos^2\theta}\,;\;\; L = (s' + vk_s)k_s\, sin\theta\,;\;\; N=0;\;\; k_1 == \frac{k_s z_v\, sin\theta}{s' + vk_s}\,;\;\; k_2=0. \qquad (11)$$

If the angle of slope of the generating strait line $\theta=0$, $z=0$, then will be received the trapezium- curved plate:

$$E = (s' + vk_s)^2\,;\;\; G = 1\,;\;\; L=N=0;\;\; k_1=k_2=0. \qquad (12)$$

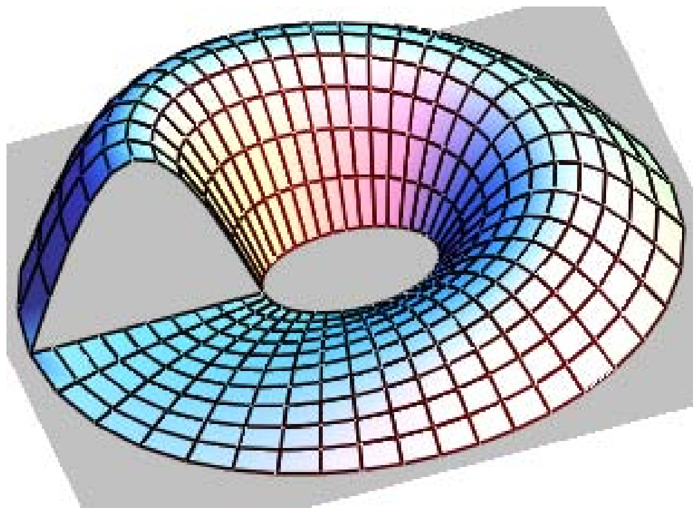

Fig. 2: Surface with ellipse directrix and sine generating curve

The geometric characteristics of surfaces with concrete directrix and generating curves will be received on the base of the common formulas of coefficient of the surfaces on trapezium-curved plans (3-11). On the fig. 2 there is shown the surface with ellipse as directrix and generating sine with linier change of its amplitude:

$$\mathbf{r}_0(u) = X(u)\mathbf{i} + Y(u)\mathbf{j}\,;\;\; X(u) = a\cos u\,;\;\; Y(u) = b\sin u\,;\;\; z(u,v) = c\frac{u}{2\pi}\sin\pi\frac{v}{d}\,;$$

$$u = 0 \div 2\pi\,;\;\; v = 0 \div d\,,$$

c is maximum amplitude of sine curve; d is the width of trapezium curved plan.

Determine parameters of the directrix ellipse and derivatives of generative curve:

$$s' = \sqrt{X'^2 + Y'^2} = a\sqrt{\eta}\,;\;\; \eta = sin^2 u + \varepsilon^2 cos^2 u\,;\;\; \varepsilon = \frac{b}{a}\,;\;\; s'' = \frac{a}{2}\frac{\eta'}{\sqrt{\eta}}\,;\;\; \eta' = (1+\varepsilon^2)sin\,2u\,;$$

$$k = \frac{X'Y'' - X''Y'}{s'^3} = \frac{\varepsilon}{a\eta^{3/2}}\,;\;\; k_s = s'k = \frac{\varepsilon}{\eta}\,;\;\; k_s' = -\frac{\varepsilon}{\eta^2}\eta' = -\varepsilon(1+\varepsilon^2)\frac{sin\,2u}{\eta^2}\,;$$

$$z_u = \frac{c}{2\pi}sin\,\pi\frac{v}{d}\,;\;\; z_{uu} = 0\,;\;\; z_{uv} = \frac{c}{2d}cos\,\pi\frac{v}{d}\,;\;\; z_v = \frac{c}{2d}u\,cos\,\pi\frac{v}{d}\,;\;\; z_{vv} = -\frac{c\pi}{2d^2}u\,sin\,\pi\frac{v}{d}\,.$$

Coefficients of the fundamental forms:

$$E=\left(a\sqrt{\eta}+v\frac{\varepsilon}{\eta}\right)^2+\frac{c^2}{4\pi^2}\sin^2\pi\frac{v}{d} \quad ; \quad G=1+\frac{c^2}{4d^2}u^2\cos^2\pi\frac{v}{d}; \quad F=\frac{c^2}{8\pi d}u\sin 2\pi\frac{v}{d};$$

$$\Sigma=\sqrt{\left(a\sqrt{\eta}+v\frac{\varepsilon}{\eta}\right)^2\left(1+\frac{c^2}{4d^2}u^2\cos^2\pi\frac{v}{d}\right)+\frac{c^2}{4\pi^2}\sin^2\pi\frac{v}{d}} \text{ -}$$

$$L=(\boldsymbol{\rho}_{uu}\boldsymbol{m})=c\frac{\frac{1+\varepsilon^2}{\pi}\left(\frac{a}{2\sin 2u}+\varepsilon\frac{v}{\eta^2}{}_s\right)\sin 2u\sin\pi\frac{v}{d}+\left(a\sqrt{\eta}+v\frac{\varepsilon}{\eta}\right)^2\frac{\varepsilon}{d}\frac{u}{\mu}\cos\pi\frac{v}{d}}{2\Sigma};$$

$$N=-\frac{c\pi}{2d^2}\frac{\left(a\sqrt{\eta}+v\frac{\varepsilon}{\eta}\right)u\sin\pi\frac{v}{d}}{\Sigma}; \quad M=-c\frac{\frac{1}{\pi}\frac{\varepsilon}{\eta}\sin\pi\frac{v}{d}+\frac{1}{d}\left(a\sqrt{\eta}+v\frac{\varepsilon}{\eta}\right)\cos\pi\frac{v}{d}}{2\Sigma}. \tag{12}$$

On the fig. 2 there is shown the Monge's surface with evolvent of the circle as directrix:

$X(u)=a(\cos u+u\sin u)$; $Y(u)=a(\sin u-u\cos u)$ and generating sine $z=b\sin\frac{v}{d}$; $u=(1\div 5)\pi$;

$v=0\div d$;

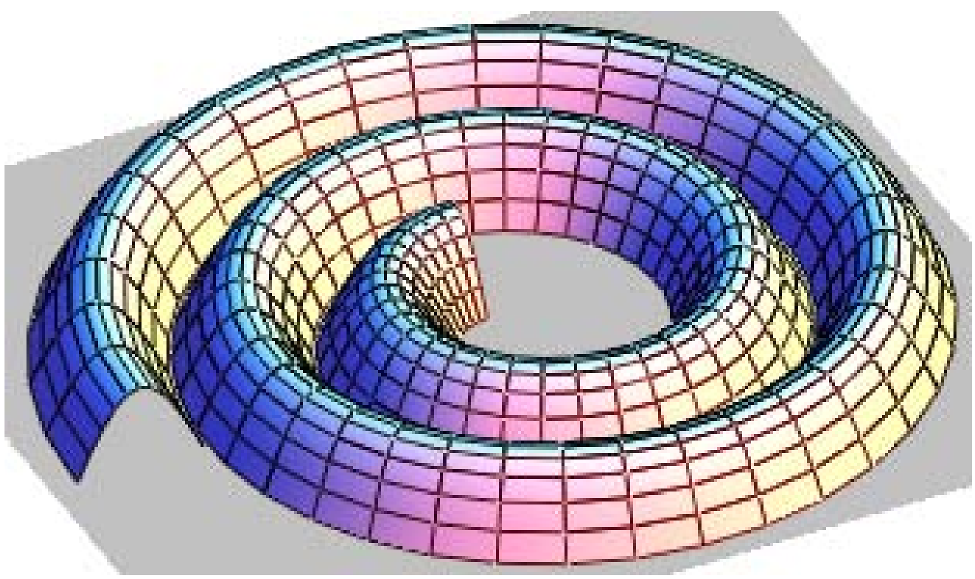

Fig. 3: Evolvent-sine Monge's surface

b is an amplitude of the sine, *d* is width of the sine (surface).
Parameters of directrix and generating curve:

$$s'=au; \quad s''=a; \quad k=\frac{1}{au}; \quad k_s=1; \quad k_s'=0;$$

$$z_v=\frac{b}{d}\cos\frac{v}{d}; \quad z_{vv}=-\frac{b}{d^2}\sin\frac{v}{d}.$$

Coefficients of the fundamental forms:

$$E=(au+v)^2;\quad G=(\boldsymbol{\rho}_v\boldsymbol{\rho}_v)=1+\frac{b^2}{d^2}cos^2\frac{v}{d};\ \Sigma=(au+v)\sqrt{1+\frac{b^2}{d^2}cos^2\frac{v}{d}};$$

$$L=\frac{b(au+v)cos\dfrac{v}{d}}{d\sqrt{1+\dfrac{b^2}{d^2}cos^2\dfrac{v}{d}}};\quad N=-\frac{b\,sin\dfrac{v}{d}}{d^2\sqrt{1+\dfrac{b^2}{d^2}cos^2\dfrac{v}{d}}};$$

$$k_1==\frac{b\,cos\dfrac{v}{d}}{d(au+v)\sqrt{1+\dfrac{b^2}{d^2}cos^2\dfrac{v}{d}}};\ k_2=-\frac{b\,sin\dfrac{v}{d}}{d^2\left(1+\dfrac{b^2}{d^2}cos^2\dfrac{v}{d}\right)^{3/2}}. \qquad (13)$$

On fig. 4 there is shown the torus surface of constant slope with Bernoulli's lemniscate as directrix:

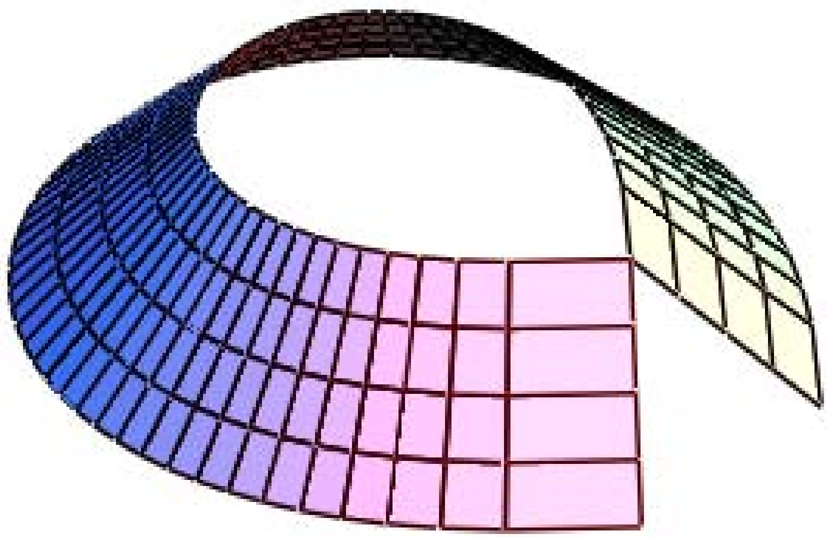

Fig. 4: Lemniscate surface of constant slope

$$X(u)=aR(u)cos\,u;\quad Y(u)=aR(u)sin\,u;$$

$$R(u)=\sqrt{2\,cos\,2u},\qquad u=(-1\div1)\pi/4.$$

$$s'=2\frac{a}{R(u)};\quad k=\frac{3}{2}\frac{R(u)}{a};\quad k_s=3.$$

The coefficients of fundamental forms and the curvatures of the surface:

$$E=\left(\frac{2a}{R(u)}+3v\right)^2;\quad G=\frac{1}{cos^2\theta};\quad L=3\left(\frac{2a}{R(u)}+3v\right)sin\,\theta;\quad k_1=3\frac{R(u)sin\,\theta}{2a+3R(u)v};\quad k_2=0. \qquad (14)$$

Let us consider the linier surfaces which aren't surfaces of constant slope.
On fig. 5 there are shone wavy linear surfaces with different directrix curves.

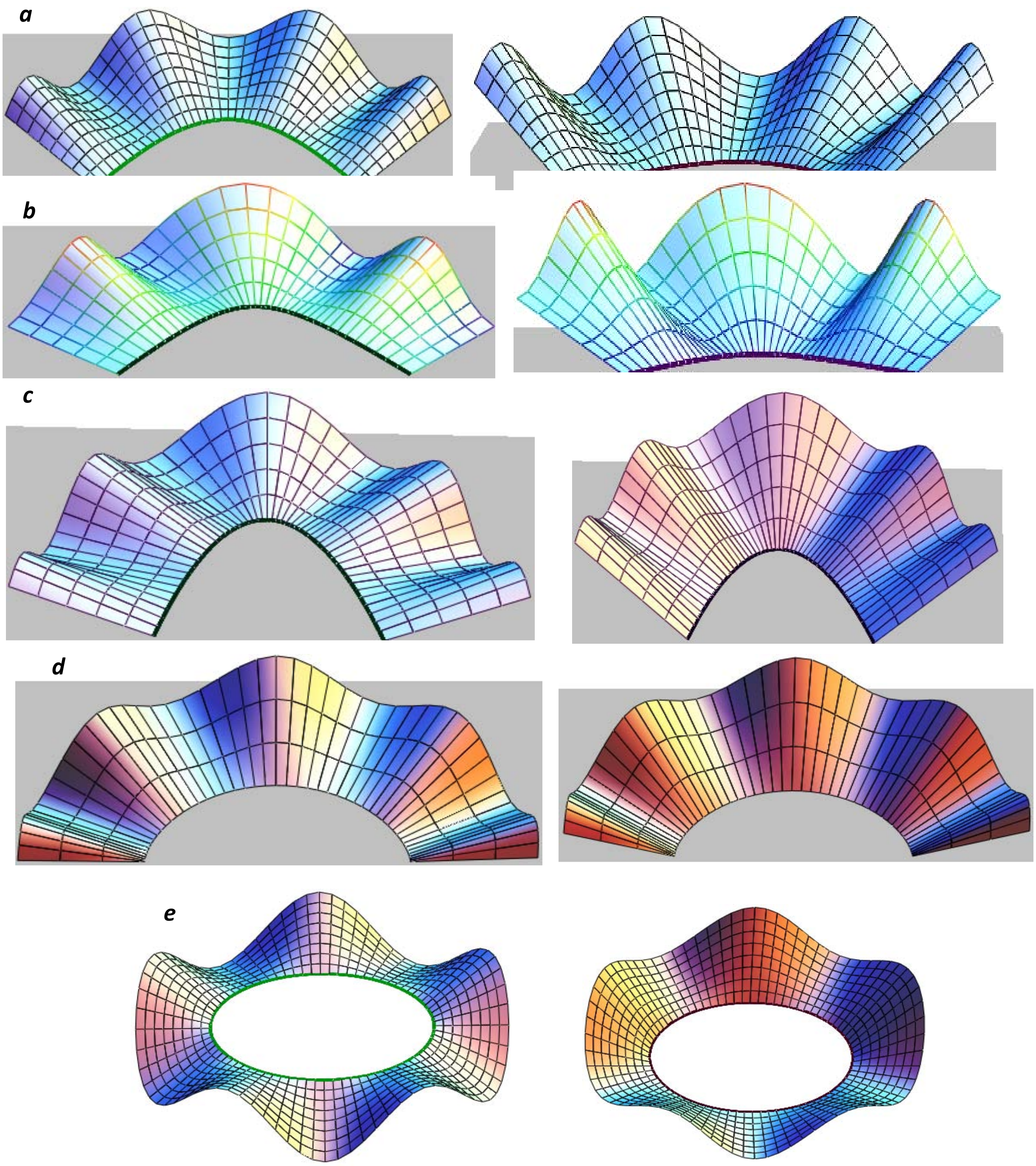

Fig. 5: Wavy linear surfaces with different directrix:
a – sine, *b* – hyperbola, *c* – parabola, *d* –cycloid, *e* - ellipse

The generating straight line at its moving along directrix made a wavy motion at the normal plane of the directrix: *a)* $z(u,v)=v(c+d\cos tu)$ or *б)* $z(u,v)=v(c+d\sin tu)$, $t=p\dfrac{\pi}{\Delta u}$, $\Delta u=u_k-u_n$ is a diapason of coordinate $v=(u_n\div u_k)$; p is a number of half waves of oscillation of the generating straight line; $c=\mathrm{tg}\theta$, θ is an angle of the generating line, around which it made the oscillations:

$$a)\quad z_u=-dtv\sin tu\,;\; z_{uu}=-dt^2v\cos tu\,;\quad z_v=c+d\cos tu\,;\quad z_{uv}=-dt\sin tu\,;\quad z_{vv}=0\,;$$

$$б)\quad z_u=dtv\cos tu\,;\; z_{uu}=-dt^2v\sin tu\,;\quad z_v=c+d\sin tu\,;\quad z_{uv}=dt\cos tu\quad z_{vv}=0\,. \qquad (15)$$

At the left row of the fig. 5 $\theta=0$, at the right row $\theta \neq 0$.

The coefficients of the fundamental forms and curvatures of these surfaces are determined on common formulas (4-9) with using formulas (19) and the fact that $N=0$, $k_v=0$.

If to take cycloid as the directrix (fig. 5,*d*) $X(u)=a(u-\sin u)$, $Y(u)=a(1-\cos u)$, $u=(0 \div 2\pi)$, we'll receive:

$$s' = 2a\sin(u/2);\ \ s'' = a\cos(u/2);\ \ k = \frac{1}{4a\sin(u/2)};\ \ k_s = \frac{1}{2};\ \ k_s' = 0;$$

$$E = \left(2a\sin(u/2) + \frac{v}{2}\right)^2 + (dtv)^2\cos^2(tu);\ \ G = 1 + (c + d\sin tu)^2;\ F = -dtv(c + d\sin tu)\sin tu;$$

$$\Sigma = \sqrt{\left[\left(2a\sin(u/2) + \frac{v}{2}\right)^2 + (dtv)^2\cos^2(tu)\right]\left[1 + (c + d\sin tu)^2\right] - \left[dtv(c + d\sin tu)\sin tu\right]^2}$$

$$L = \left[adtv\cos^2(u/2) + \left(2a\sin(u/2) + \frac{v}{2}\right)^2 \frac{c + d\cos tu}{2} - \left(2a\sin(u/2) + \frac{v}{2}\right)dt^2 v\cos tu\right]\frac{1}{\Sigma};$$

$$M = \frac{dt}{2}\frac{v(\sin tu - \cos tu) - 4a\sin(u/2)\cos tu}{\Sigma};\quad N=0. \tag{15}$$

II. Conclusion

The surfaces on the trapezium curved plans are formed by the moving of some generating curve at the normal plane of directrix curve. The generative curve may change its form when it is moving along the directrix, but has the constant wide of the plan. At the article there is received the vector equation of the surfaces on trapezium curved plans. On the base of the vector equation there are received the coefficients of the fundamental forms and the curvatures of the surfaces. If the function of vertical coordinates depends on coordinate parameter of the directrix (the form of generating curve changes at moving along the directrix), then the coordinate system of the surface isn't orthogonal and isn't conjugated. If along directrix there moving unchangeable curve then the coordinate lines of the surface are lines of principle curvatures and this type of surfaces is applied to the class of Monge's surfaces [5, 7-9]. On the base of common formulas there are received the formulas of geometric characteristics of the Monge's surfaces. If at the normal plane of the directrix there is moving a straight line with the constant slope to the directrix plane, then there will be received the torus surface of constant slope. Those type of surfaces belong to the class of Monge's surfaces as well.

On the base of common formulas of investigated class there are received the formulas of the surfaces and their geometric characteristics of the surfaces with concrete directrix and generating curves, as for surfaces of common type and so for Monge's and surfaces of constant slope. The using of common formulas made more simple the proses for receiving formulas for concrete surfaces. For every investigated surface there are given their figures.

Also there was investigated the type of wavy surfaces formed by the generating straight line which make oscillations at the normal plane of directrix. There are received the formulas of the geometric characteristics of this type of surfaces and given the figures of wavy line surfaces with some directrix lines.

The figures of the surfaces were made with using of vector equations of the surfaces in the "MathCad" system [5, 13]

References Références Referencias

1. *Ivanov V.N., ., Imomnazarov T.S., Farhan I.T.* Orthogonal Curved Coordinate System and Forming the Surfaces on Trapezium-Curved Plans. –Vestnic of Russian Friendship University. Ser.: Engineering Investigations. -2017. T. 18. - № 4. – P.p. 518-527. DOI: 10.22363/2312-8143-18-4-518-527. http://journals. rudn.ru/tnginttring-researches
2. Shulikovskiy V.I. Classical differential Geometry. Moscow, GIFVL, 1963, 540 p.
3. Forsyth A.R. Lectures on the Differential Geometry of Curves and Surfaces. – Cambridge. – 1920.
4. *V.N. Ivanov*. Geometry and forming of the normal surfaces with system of plane coordinate lines. – Structural mechanics of engineering constructions and buildings. - 2011. – № 4. – P. 6-14.
5. *Ivanov V.N., Romanova V.A.* Constructive forms of space constructions. Visualization of the surfaces at the systems "MathCAD", and "AutoCAD". - Monograph. – Moskow: Izd-vo ASV, 2016. – 412 p.

6. *Иванов В.Н.*, *Шмелева А.А.* Геометрия и формообразование тонкостенных пространственных конструкций на основе нормальных циклических поверхностей. Строительная механика инженерных конструкций и сооружений. – 2016. – № 6. – С. 3-8
7. *Monge G*. Application of analysis to Geometry. Moscow, ONTI, 1936.
8. *Ivanov V.N*., *Rizvan Muhammad*. Geometry of Monge surfaces and construction of the shells// Structural mechanics of engineering constructions and buildings/ Mezhvuzovskie sbornic of science works. –Vip. 11. – Moscow: Izd-vo ASV, 2002. – P. 27-36.
9. B. Bulca, K. Arslan, "Surfaces Given with the Monge Patch in E4E4", Jour. Math. phis., Analit., Geom., 9:4, p. 435–447. (2013).
10. S.*N. Krivoshapko, V.N. Ivanov*. Encyclopedia of Analytical Surfaces. Springer International Publishing Switzerland, 2015. - 752 p.
11. *Ivanov V.N., Alyoshina O.O*. Comparative analysis of the results of determining the parameters of the stress-strain state of equal slopes shell.
12. *Krivoshapko S.N.* Geometry of ruled surfaces with cuspidal edge and the linear theory of analysis of torus shells. – Monograph. – Moscow: RUDN, 2009. – 357 p.
13. Ivanov V.N. Constructing shells and their visualization in system "MathCad" on basis of vector equations of surfaces. IOP Conference Series: Materials Science and Engineering 456 (2018) 012018, 2019. Doi: 10.1088/1757-899X/456/1/012018

Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

An Experimental Study on the Strength Properties of Geopolymer Bricks

By Sudhikumar G S
Channabasaveshwara Institute of Technology

Abstract- This paper presents the experimental investigation by partial replacement of fly ash by GGBS on geopolymer bricks. The bricks were of a standard size of 190 mm x 90 mm x 90 mm. In this investigation, a geopolymer brick was prepared by the partial replacement of fly ash by GGBS (50:50), fine aggregates, and six molar concentrations of sodium hydroxide and sodium silicate (Na_2SiO_3) solution were used as an alkaline solution with a mass ratio of $Na_2SiO_3/NaOH$ of 2.5. The geopolymer bricks were kept open to the atmosphere for 24 hours. The geopolymer brick specimen was tested for water absorption and compressive strength. The strength of the masonry depends on the strength of the component of the masonry such as bricks and cement mortar. Triplet shear bond and Single shear bond strengths was calculated. The test results showed that the compressive strength increases with 100% replacement of GGBS with fly ash. Since the minimum compressive strength of brick is limited to 3.5 N /mm^2, a 50% replacement of GGBS with fly ash was studied for all the tests.

Keywords: *alkali solution, fly ash, GGBS, geo-polymer, sodium hydroxide, sodium silicate.*

GJRE-E Classification: *FOR Code: 090599*

ANEXPERIMENTALSTUDYONTHESTRENGTHPROPERTIESOFGEOPOLYMERBRICKS

Strictly as per the compliance and regulations of:

An Experimental Study on the Strength Properties of Geopolymer Bricks

Sudhikumar G S

Abstract- This paper presents the experimental investigation by partial replacement of fly ash by GGBS on geopolymer bricks. The bricks were of a standard size of 190 mm x 90 mm x 90 mm. In this investigation, a geopolymer brick was prepared by the partial replacement of fly ash by GGBS (50:50), fine aggregates, and six molar concentrations of sodium hydroxide and sodium silicate (Na_2SiO_3) solution were used as an alkaline solution with a mass ratio of $Na_2SiO_3/NaOH$ of 2.5. The geopolymer bricks were kept open to the atmosphere for 24 hours. The geopolymer brick specimen was tested for water absorption and compressive strength. The strength of the masonry depends on the strength of the component of the masonry such as bricks and cement mortar. Triplet shear bond and Single shear bond strengths was calculated. The test results showed that the compressive strength increases with 100% replacement of GGBS with fly ash. Since the minimum compressive strength of brick is limited to 3.5 N /mm^2, a 50% replacement of GGBS with fly ash was studied for all the tests.

Keywords: alkali solution, fly ash, GGBS, geo-polymer, sodium hydroxide, sodium silicate.

I. Introduction

Masonry is constructed with bricks and mortar. Masonry walls are cheap, and have good sound and insulation properties. The surface characteristics of the brick may not influence the bond between the bricks. Venumadhava Rao et al. 1995 made a preliminary study on the influence of bond strength on the compressive strength of masonry. Goodwin and West (1992) McGinley (1990) suggested that both the mortar quality and the surface absorption criteria of the masonry unit are the most significant parameters in developing good bond strength.

II. Objectives

This experimental study has aimed at following objectives

- To produce Geopolymer bricks with partial replacement of Fly ash by GGBS (50:50)
- To determine the percentage of water absorption and compressive strength of Geopolymer bricks (Fly ash to GGBS, 50:50) and compared with the locally available burnt clay bricks.
- To determine Triplet shear and shear bond strength of Geopolymer bricks (Fly ash to GGBS, 50:50) and compared with the locally available burnt clay bricks.

III. Methodology

- Geopolymer bricks were prepared with partial replacement of Fly ash by GGBS varying from 0 to 100%.
- Compressive strength was determined for all replacement for Fly ash - GGBS (50:50). The minimum compressive strength of burnt clay bricks (3.5 N / mm^2) was taken as the base for further tests.
- The water absorption test is carried out for burnt clay and Geopolymer bricks Fly ash- GGBS (50:50).
- Triplet shear and Shear bond strength is carried out for burnt clay and Geopolymer bricks, Fly ash by GGBS (50:50).

IV. Material Properties

Clay bricks and a Geopolymer fly ash brick partially replaced by GGBS was used to study the strength properties of the masonry unit. The compressive strength of burnt clay brick and Geopolymer bricks (varying percentage of GGBS replaced to fly ash), are being presented in Table 1 & 2, The water absorption of burnt clay brick and Geopolymer bricks (Fly ash: GGBS, 50:50) are shown in Table 3 & 4. Comparison of water absorption of burnt clay bricks and Geo-polymer bricks (Fly ash: GGBS, 50:50) are shown in Fig 1, Triplet shear bond strength with 1:6 cement mortar of burnt clay brick and Geopolymer bricks (Fly ash: GGBS, 50:50) are tabulated in Table 5 & 6, Comparison of triplet shear bond strength of burnt clay bricks are shown in Fig 2 and Shear bond strength with 1:6 cement mortar of burnt clay brick and Geopolymer bricks (Fly ash: GGBS, 50:50) are being presented in Table 7 & 8. Comparison of Shear bond strength of burnt clay bricks and Geopolymer bricks (Fly ash: GGBS, 50:50) are revealed in Fig 3.

Author: Professor, Department of Civil Engineering, Channabasaveshwara Institute of Technology, Gubb.
e-mail: sudhikumar.gs@cittumkur.org

V. Tables and Figures

Table 1: Compressive strength- Burnt clay bricks

Sl. No.	Size of burnt clay bricks (mm)	Area (mm^2)	Load (KN)	Compressive strength (N / mm^2)	Average compressive Strength (N/mm^2)
1	(220 x 100 x 75)	22000	112	5.09	5.25
2			126	5.72	
3			098	4.45	
4			126	5.73	
5			116	5.27	

Table 2: Compressive strength- Geopolymer bricks (Fly ash: GGBS, 50:50)

Sl. No.	Fly ash: GGBS	Average compressive strength (N / mm^2)
1	100 : 00	00.87
2	90 : 10	01.35
3	80 : 20	02.04
4	70 : 30	02.45
5	60 : 40	03.50
6	50 : 50	03.97
7	40 : 60	04.50
8	30 : 70	04.93
9	20 : 80	06.04
10	10 : 90	06.60
11	0 : 100	07.45

Table 3: Water absorption test - Burnt clay bricks

Sl. No.	Dry weight (Kg)	Wet weight (Kg)	Water absorption (%)	Avg. water absorption (%)
1	3.48	3.15	10.47	9.69
2	3.43	3.11	10.28	
3	3.40	3.12	08.97	
4	3.45	3.15	09.52	
5	3.41	3.12	09.23	

Table 4: Water absorption test - Geopolymer bricks (Fly ash: GGBS, 50:50)

Sl. No.	Dry weight (Kg)	Wet weight (Kg)	Water absorption (%)	Avg. water absorption (%)
1	3.01	3.28	8.97	9.11
2	3.00	3.24	9.66	
3	2.96	3.24	9.66	
4	3.02	3.32	9.93	
5	2.97	3.26	8.89	

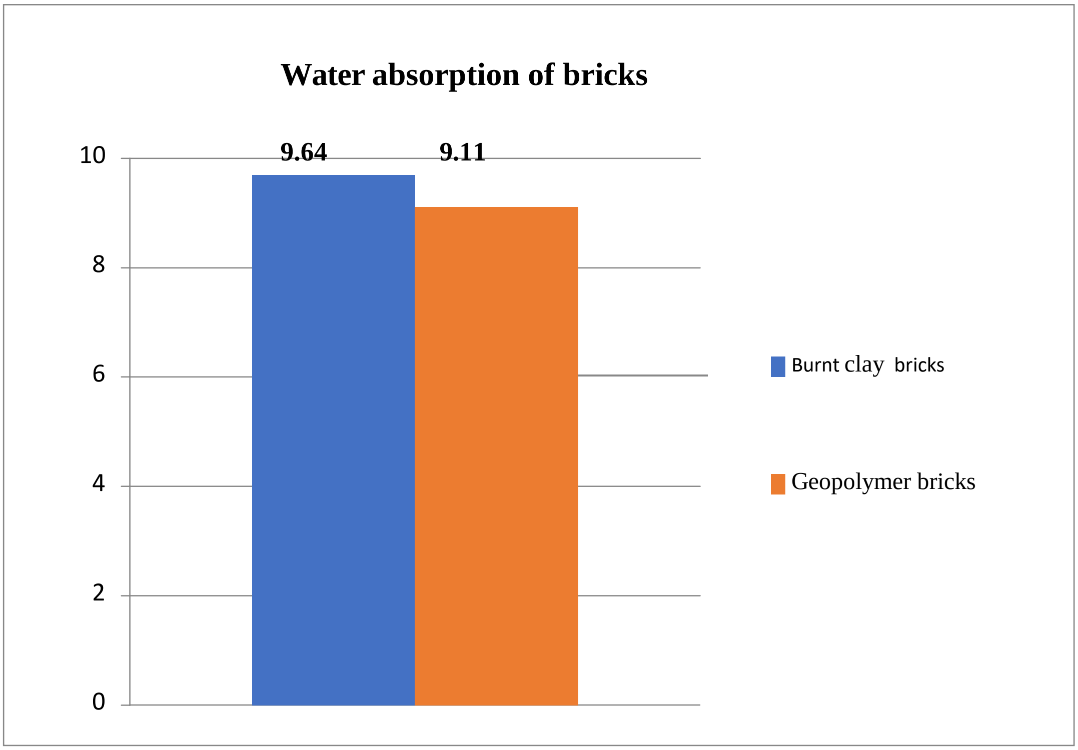

Fig. 1: Comparison of water absorption of burnt clay bricks and Geo-polymer bricks (Fly ash:GGBS, 50:50)

Table 5: Triplet shear bond strength – Burnt clay bricks

Sl. No.	Load (KN)	Size of brick (mm)	Area of brick (mm^2)	Shear bond strength	Avg. shear bond strength (N/mm^2)
1	2.80			0.063	
2	3.00			0.068	
3	2.90	(220 x 100 x 75)	22000	0.065	0.064
4	2.80			0.063	
5	2.79			0.063	

Table 6: Triplet shear bond strength of Geopolymer bricks (Fly ash: GGBS, 50:50)

Sl. No.	Load (KN)	Size of brick (mm)	Area of brick (mm^2)	Shear bond strength	Avg. shear bond strength (N/mm^2)
1	3.8			0.172	
2	3.7			0.168	
3	3.6	(220 x 100 x 75)	22000	0.163	0.168
4	3.7			0.168	
5	3.8			0.172	

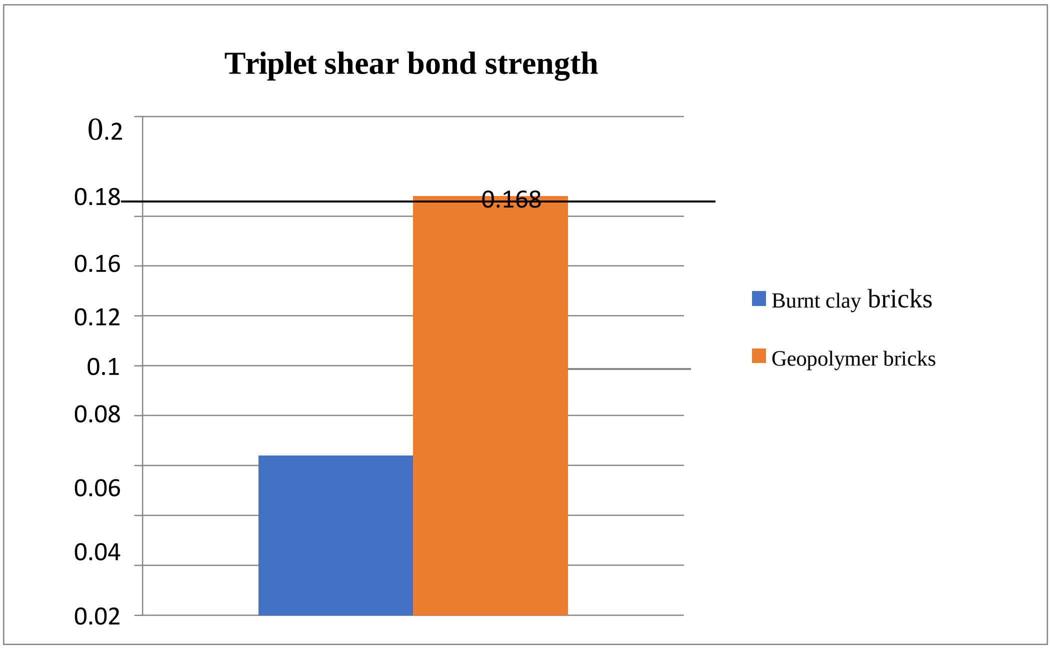

Fig. 2: Comparison of Triplet shear bond strength of Burnt clay bricks and Geo-polymer bricks (Fly ash: GGBS, 50:50)

Table 7: Shear bond strength – Burnt clay bricks

Sl. No.	Load (KN)	Size of brick (mm)	Area of brick (mm^2)	Shear bond strength	Avg. shear bond strength (N/mm^2)
1	0.8	(220 x 100 x 75)	22000	0.106	0.114
2	0.8			0.106	
3	0.9			0.120	
4	0.9			0.120	
5	0.9			0.120	

Table 8: Shear bond strength of Geopolymer bricks (Fly ash: GGBS, 50:50)

Sl. No.	Load (KN)	Size of brick (mm)	Area of brick (mm^2)	Shear bond strength	Avg. shear bond strength (N/mm^2)
1	3.8	(220 x 100 x 75)	22000	0.222	0.217
2	3.7			0.216	
3	3.6			0.210	
4	3.7			0.216	
5	3.8			0.222	

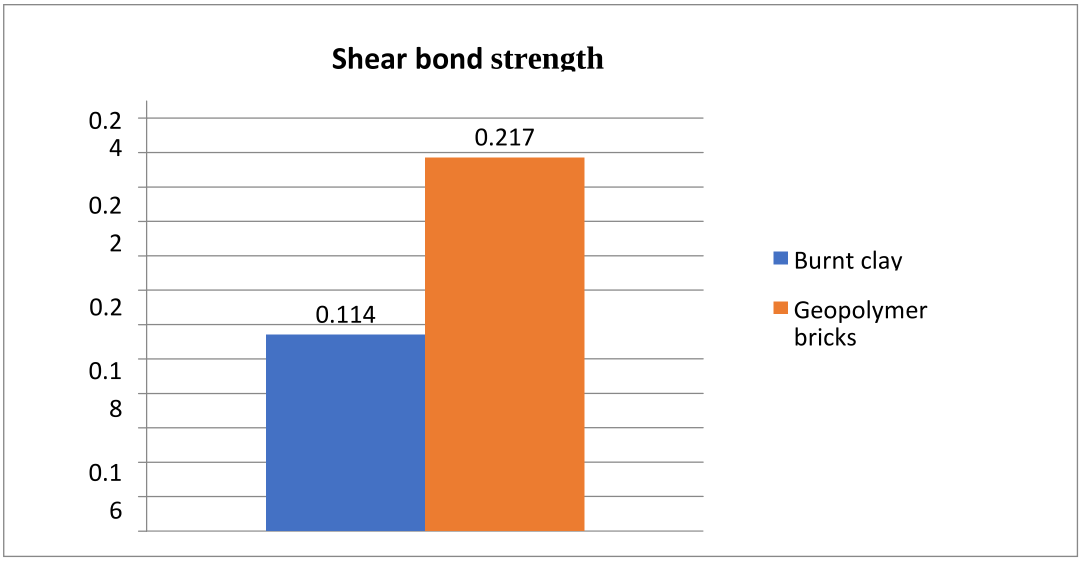

Fig. 3: Comparison of Single shear bond strength of Burnt clay bricks and Geo-polymer bricks (Fly ash: GGBS, 50:50)

VI. Conclusions

- It was observed that the compressive strength of Geopolymer bricks with partial replacement of Fly ash with GGBS increases up to 100%. The compressive strength of burnt clay brick is 3.5 N/mm^2; the substitute of fly ash to GGBS is (50:50).
- It was observed that the percentage of water absorption of Geopolymer bricks is 5.90% less than the ordinary burnt clay bricks.
- It was observed that the triplet shear bond strength, with 1:6 cement mortar, strength of Geopolymer bricks was 62% greater than ordinary burnt clay bricks.
- It was observed that the shear bond strength with 1:6 cement mortar, Geopolymer bricks are 48% greater than ordinary burnt clay bricks.
- Incorporation of GGBS as partial replacement to Fly ash in the preparation of Geopolymer bricks resulted in the reaction of pozzolana with calcium hydrate which produced calcium silicate hydrate, thus enhancing the compressive strength and shear bond strength of the brick masonry with the modification of the microstructure of the mortar – brick unit interface.

Acknowledgements

The author would like to thank Dr. D S Suresh, Director, and Principal, C I T. Gubbi, for the encouragement throughout the work. The author is also indebted to management authorities for their wholehearted support. The author is also grateful to all the teaching & nonteaching faculties for their encouragement.

Global Journals Guidelines Handbook 2020

www.GlobalJournals.org

Memberships

FELLOWS/ASSOCIATES OF ENGINEERING RESEARCH COUNCIL

FERC/AERC MEMBERSHIPS

Introduction

FERC/AERC is the most prestigious membership of Global Journals accredited by Open Association of Research Society, U.S.A (OARS). The credentials of Fellow and Associate designations signify that the researcher has gained the knowledge of the fundamental and high-level concepts, and is a subject matter expert, proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice. The credentials are designated only to the researchers, scientists, and professionals that have been selected by a rigorous process by our Editorial Board and Management Board.

Associates of FERC/AERC are scientists and researchers from around the world are working on projects/researches that have huge potentials. Members support Global Journals' mission to advance technology for humanity and the profession.

FERC

FELLOW OF ENGINEERING RESEARCH COUNCIL

FELLOW OF ENGINEERING RESEARCH COUNCIL is the most prestigious membership of Global Journals. It is an award and membership granted to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Fellows are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Fellow Members.

Benefit

To the institution

Get letter of appreciation

Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

Exclusive Network

Get access to a closed network

A FERC member gets access to a closed network of Tier 1 researchers and scientists with direct communication channel through our website. Fellows can reach out to other members or researchers directly. They should also be open to reaching out by other.

Career | Credibility | Exclusive | Reputation

Certificate

Certificate, LoR and Laser-Momento

Fellows receive a printed copy of a certificate signed by our Chief Author that may be used for academic purposes and a personal recommendation letter to the dean of member's university.

Career | Credibility | Exclusive | Reputation

Designation

Get honored title of membership

Fellows can use the honored title of membership. The “FERC” is an honored title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., FERC or William Walldroff, M.S., FERC.

Career | Credibility | Exclusive | Reputation

Recognition on the Platform

Better visibility and citation

All the Fellow members of FERC get a badge of "Leading Member of Global Journals" on the Research Community that distinguishes them from others. Additionally, the profile is also partially maintained by our team for better visibility and citation. All fellows get a dedicated page on the website with their biography.

Career | Credibility | Reputation

Future Work

Get discounts on the future publications

Fellows receive discounts on the future publications with Global Journals up to 60%. Through our recommendation programs, members also receive discounts on publications made with OARS affiliated organizations.

Career Financial

GJ Account

Unlimited forward of Emails

Fellows get secure and fast GJ work emails with unlimited storage of emails that they may use them as their primary email. For example, john [AT] globaljournals [DOT] org.

Career Credibility Reputation

Premium Tools

Access to all the premium tools

To take future researches to the zenith, fellows receive access to all the premium tools that Global Journals have to offer along with the partnership with some of the best marketing leading tools out there.

Financial

Conferences & Events

Organize seminar/conference

Fellows are authorized to organize symposium/seminar/conference on behalf of Global Journal Incorporation (USA). They can also participate in the same organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent. Additionally, they get free research conferences (and others) alerts.

Career Credibility Financial

Early Invitations

Early invitations to all the symposiums, seminars, conferences

All fellows receive the early invitations to all the symposiums, seminars, conferences and webinars hosted by Global Journals in their subject.

Exclusive

Publishing Articles & Books

Earn 60% of sales proceeds

Fellows can publish articles (limited) without any fees. Also, they can earn up to 70% of sales proceeds from the sale of reference/review books/literature/publishing of research paper. The FERC member can decide its price and we can help in making the right decision.

Exclusive Financial

Reviewers

Get a remuneration of 15% of author fees

Fellow members are eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get a remuneration of 15% of author fees, taken from the author of a respective paper.

Financial

Access to Editorial Board

Become a member of the Editorial Board

Fellows may join as a member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. Additionally, Fellows get a chance to nominate other members for Editorial Board.

Career Credibility Exclusive Reputation

And Much More

Get access to scientific museums and observatories across the globe

All members get access to 5 selected scientific museums and observatories across the globe. All researches published with Global Journals will be kept under deep archival facilities across regions for future protections and disaster recovery. They get 10 GB free secure cloud access for storing research files.

ASSOCIATE OF ENGINEERING RESEARCH COUNCIL

ASSOCIATE OF ENGINEERING RESEARCH COUNCIL is the membership of Global Journals awarded to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

> The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Associate membership can later be promoted to Fellow Membership. Associates are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Associate Members.

Benefit

To the Institution

Get letter of appreciation

Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

Exclusive Network

Get access to a closed network

A AERC member gets access to a closed network of Tier 1 researchers and scientists with direct communication channel through our website. Associates can reach out to other members or researchers directly. They should also be open to reaching out by other.

Career | Credibility | Exclusive | Reputation

Certificate

Certificate, LoR and Laser-Momento

Associates receive a printed copy of a certificate signed by our Chief Author that may be used for academic purposes and a personal recommendation letter to the dean of member's university.

Career | Credibility | Exclusive | Reputation

Designation

Get honored title of membership

Associates can use the honored title of membership. The “AERC” is an honored title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., AERC or William Walldroff, M.S., AERC.

Career | Credibility | Exclusive | Reputation

Recognition on the Platform

Better visibility and citation

All the Associate members of AERC get a badge of "Leading Member of Global Journals" on the Research Community that distinguishes them from others. Additionally, the profile is also partially maintained by our team for better visibility and citation. All associates get a dedicated page on the website with their biography.

Career | Credibility | Reputation

Future Work

Get discounts on the future publications

Associates receive discounts on the future publications with Global Journals up to 60%. Through our recommendation programs, members also receive discounts on publications made with OARS affiliated organizations.

Career Financial

GJ Account

Unlimited forward of Emails

Associates get secure and fast GJ work emails with unlimited storage of emails that they may use them as their primary email. For example, john [AT] globaljournals [DOT] org..

Career Credibility Reputation

Premium Tools

Access to all the premium tools

To take future researches to the zenith, associates receive access to all the premium tools that Global Journals have to offer along with the partnership with some of the best marketing leading tools out there.

Financial

Conferences & Events

Organize seminar/conference

Associates are authorized to organize symposium/seminar/conference on behalf of Global Journal Incorporation (USA). They can also participate in the same organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent. Additionally, they get free research conferences (and others) alerts.

Career Credibility Financial

Early Invitations

Early invitations to all the symposiums, seminars, conferences

All associates receive the early invitations to all the symposiums, seminars, conferences and webinars hosted by Global Journals in their subject.

Exclusive

Publishing Articles & Books

Earn 30-40% of sales proceeds

Associates can publish articles (limited) without any fees. Also, they can earn up to 30-40% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.

Exclusive Financial

Reviewers

Get a remuneration of 15% of author fees

Associate members are eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get a remuneration of 15% of author fees, taken from the author of a respective paper.

Financial

And Much More

Get access to scientific museums and observatories across the globe

All members get access to 2 selected scientific museums and observatories across the globe. All researches published with Global Journals will be kept under deep archival facilities across regions for future protections and disaster recovery. They get 5 GB free secure cloud access for storing research files.

Associate	Fellow	Research Group	Basic
$4800 **lifetime designation**	$6800 **lifetime designation**	$12500.00 **organizational**	APC **per article**
Certificate, LoR and Momento 2 discounted publishing/year **Gradation** of Research 10 research contacts/day **1 GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day **5 GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

Before and during Submission

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

Policy on Plagiarism

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

Authorship Policies

Global Journals follows the definition of authorship set up by the Open Association of Research Society, USA. According to its guidelines, authorship criteria must be based on:

1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

Copyright

During submission of the manuscript, the author is confirming an exclusive license agreement with Global Journals which gives Global Journals the authority to reproduce, reuse, and republish authors' research. We also believe in flexible copyright terms where copyright may remain with authors/employers/institutions as well. Contact your editor after acceptance to choose your copyright policy. You may follow this form for copyright transfers.

Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

CRITERION FOR GRADING A RESEARCH PAPER (COMPILATION) BY GLOBAL JOURNALS

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

INDEX

save our planet

Global Journal of Researches in Engineering

Visit us on the Web at www.GlobalJournals.org | www.EngineeringResearch.org
or email us at helpdesk@globaljournals.org

ISSN 9755861