Surfaces on Trapezium-Curved Plans

Analysis of Sustainable Indicators

Properties of Geopolymer Bricks

Utilization of the Three-Dimensional

Discovering Thoughts, Inventing Future

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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

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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

Kei 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 main tenance 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.

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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（リサイクル、LCA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。

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、基本的にはごく限定さ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、桜井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面、欠損した地表面に対し、土工事の出来高管理
表1: 3次元点群データ計測手法の比較

| 手法 | レーザ光線を発して、物体に照射して計測
| 空撮測量 | UAV（Unmanned Aerial Vehicle）

内容

| 内容 | レーザ光線を発して、物体に照射して計測
| 空撮測量 | UAV（Unmanned Aerial Vehicle）

性能

| 性能 | ①固定式地上レーザ計測 (精度:数mm程度)
| 空撮測量 | 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できる。
| ②MMS (Mobile Mapping System)
| 空撮測量 | 空撮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。
| ③航空レーザ測量 (精度:10cm程度) | 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

次の通り、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、公共土木工事に基づく効果を抽出し、公共土木工事に基づく効果を抽出し、維持管理に必要な属性情報を選定している。また、宮武(8)(9)(10)らは、築堤工事においてCIMを適用した試行工事を通じて設計照査、施工計画、測量、施工・設計変更、検証までの各観点において、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的位置づけや役割、運用上の課題について述べている。また、宮崎(11)らは、河川工事においてCIMを適用し、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、経絡变化の可視化や過去の変遷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に寄与する効果を検証している。田中(14)、清水(15)、山岡(16)らは、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。

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、公共土木工事に基づく効果を抽出し、維持管理に必要な属性情報を選定している。また、宮武(8)(9)(10)らは、築堤工事においてCIMを適用した試行工事を通じて設計照査、施工計画、測量、施工・設計変更、検証までの各観点において、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的位置づけや役割、運用上の課題について述べている。また、宮崎(11)らは、河川工事においてCIMを適用し、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、経絡変化の可視化や過去の変遷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。

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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を、維持管理情報としての利用活用の可能性について記述しており、非常に有益なものである。また、3次元モデルの作成手法を選択した側面について言及したものは少ない。CIMやi-Constructionの概念は、計画から検証、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り、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、かつその作成作業を通じて建設工事の過程において3次元モデルが有効に活用できるかは、技術内容、規模、工種によって異なると考えられる。

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ついての検証を試みた。
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間隔を把握することが施工前に要求されたため、3次元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有効性を高めるために高精度でモデル化することが要求されたため、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。測量計画は、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、鉄筋の組立工事に関しては、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鋼材が複数の交差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、組立てることで各コンクリート工事を支障となる箇所を把握することとした（図-3、図-4）。

写真-1工事箇所工事前状況

図-1 3次元点群データ

図-2 3次元モデル
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した。

盛土材の敷設作業は、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、運転席で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）。

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、設計図面よりも最終仕上がり形状を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、運転計画を立てることができた。
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を送受信を可能にし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状況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）。

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、締固め回数等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を用い、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

写真-10 バケット角度保持モード

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用計画、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、基本的には測量杭は不要となり、丁張り設置や検測作業がなくなり、測量作業の効率化を図ることができた。また、施工時の丁張りを目的にした点と線の管理に代わり、モニタ画面で施工範囲の面的な管理を行うことにより、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になった。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、施工情報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）を入力することにより、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き渡しを行った。

掘削時は、切羽観察情報を 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、覆工ブロックをクリックすると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トンネル縦断図、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、大規模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）、崖壁堆積物（dt）が累積する。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地質モデルを推定した。走向方向は、地形データから低地帯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）と破砕帯を全体の 3 次元モデルに加え込んだものを図-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）。
b) 導入による効果

今回、維持管理業務への活用という観点で \(^3\) 次次元モデル作成を行った。 脆弱帯や破砕帯区間を基に \(^3\) 次次元モデルを作成し、地質情報が変更されたとき、容易にデータを反映できる。 さらに、\(^3\) 次次元モデル作成により、 \(^3\) 次次元データが遊写し、施工情報と地質情報が関連付けられている。

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応じた \(^3\) 次元モデル作成手法、施工生産プロセスにおける活用方法を導入した。施工前には既存構造物と \(^3\) 次次元モデル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、 \(^3\) 次次元モデル作成に取り入れることで、従来の方法より短時間で土工量算出できる。さらに、\(^3\) 次次元データを基にしたICT機器の稼働により、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、 \(^3\) 次次元モデル作成に取り入れることで、 \(^3\) 次次元データを基にしたICT機器の稼働により、施工の効率化と品質向上に効果を発揮した。

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

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

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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.

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

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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.

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1. 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

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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 Gudmundsson, 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 Gudmundsson, 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

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

Table 2: State level rating system and their developers

<table>
<thead>
<tr>
<th>Sustainability rating system</th>
<th>Developers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green roads certification</td>
<td>Washington Department of Transportation and the University of Washington</td>
</tr>
<tr>
<td>GreenLITES certification</td>
<td>New York Department of Transportation</td>
</tr>
<tr>
<td>I-LAST</td>
<td>Illinois Department of Transportation</td>
</tr>
<tr>
<td>BE2ST</td>
<td>Wisconsin Department of Transportation and the University of Wisconsin.</td>
</tr>
</tbody>
</table>

Table 3: Local, sustainable rating systems and their developers

<table>
<thead>
<tr>
<th>Sustainability rating system</th>
<th>Developers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable transportation and analysis rating systems(STAR)</td>
<td>Portland Department of Transportation, Oregon</td>
</tr>
<tr>
<td>PEACH Roads</td>
<td>Cobb County, Georgia</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Invest (%)</th>
<th>Envision (%)</th>
<th>Green Roads (%)</th>
<th>PEACH Roads (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation planning</td>
<td>12</td>
<td>13</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>ITS</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>Multi Transit</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Intermodal</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Safety</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Emissions</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>29</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

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 Gudmundsson, 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 Gudmundsson, 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 influence 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 influence sustainability and are 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)

<table>
<thead>
<tr>
<th>Sustainable indicators</th>
<th>Data sources</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total state budget</td>
<td>Sunshine Review</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Total budget on transportation</td>
<td>Sunshine Review</td>
<td>High to Medium</td>
</tr>
<tr>
<td>The budget on public transportation</td>
<td>Sunshine Review</td>
<td>High to Medium</td>
</tr>
<tr>
<td>The budget on sustainable programs</td>
<td>Sunshine Review</td>
<td>High to Medium</td>
</tr>
<tr>
<td>The budget for sustainable research</td>
<td>Sunshine Review</td>
<td>High to Medium</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sustainable indicators</th>
<th>Data sources</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ridership of public transport</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on high-speed rail</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on commuter rail</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on buses</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on carpool/vanpool</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on trolleybuses</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on streetcars</td>
<td>American Public transit Association (APTA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ridership on bicycle</td>
<td>American Public transit Association (APTA)</td>
<td>Medium to Low</td>
</tr>
<tr>
<td>Ridership on demand response</td>
<td>American Public transit Association (APTA)</td>
<td>Low</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sustainable indicators</th>
<th>Data sources</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon emissions by public transportation</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Carbon emissions by state buildings</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Gasoline consumption</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Ethanol consumption</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Biofuel productions</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sustainable indicators</th>
<th>Data sources</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation energy</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Operational energy</td>
<td>Environmental Protection Agency (EPA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Embodied energy</td>
<td>Environmental Protection Agency (EPA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>State vehicles on alternative fuels</td>
<td>Energy Information Administration (EIA)</td>
<td>High to Medium</td>
</tr>
<tr>
<td>State vehicles on electricity</td>
<td>Federal Highway Administration (FHWA)</td>
<td>High to Medium</td>
</tr>
</tbody>
</table>
**Table 10:** State agencies' commitments and goals

<table>
<thead>
<tr>
<th>Sustainable indicators</th>
<th>Data sources</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainability targets</td>
<td>DOT/Survey</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Participation in livability programs</td>
<td>DOT/Survey</td>
<td>Medium to Low</td>
</tr>
<tr>
<td>Public involvement and educational programs</td>
<td>Survey</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Environment management systems by state DOTs</td>
<td>Survey</td>
<td>High to Medium</td>
</tr>
<tr>
<td>Green highway initiatives</td>
<td>DOT/Survey</td>
<td>High to Medium</td>
</tr>
</tbody>
</table>

**Table 11:** Other important indicators

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

**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 Gudmundsson, 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.
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 adjustor 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 adjustor.

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)

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

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 analysis.
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 indicators 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>
<thead>
<tr>
<th>S. No.</th>
<th>Indicators</th>
<th>Pearson's correlation</th>
<th>Rank correlation</th>
<th>P-value</th>
<th>High to Medium</th>
<th>Medium to Low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transportation Budget</td>
<td>0.462</td>
<td>0.81</td>
<td>0.179</td>
<td>☐</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>2</td>
<td>Automobiles</td>
<td>0.568</td>
<td>0.40</td>
<td>0.011</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
</tr>
<tr>
<td>3</td>
<td>Ridership</td>
<td>0.472</td>
<td>0.64</td>
<td>0.582</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>4</td>
<td>Carbon emission</td>
<td>0.303</td>
<td>0.18</td>
<td>0.069</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5</td>
<td>Ethanol Consumption</td>
<td>0.311</td>
<td>0.93</td>
<td>0.035</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>6</td>
<td>Gasoline consumption</td>
<td>0.314</td>
<td>0.36</td>
<td>0.020</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7</td>
<td>Transportation energy consumption</td>
<td>0.310</td>
<td>0.24</td>
<td>0.013</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>S. No.</th>
<th>Indicators</th>
<th>Pearson's Correlation</th>
<th>Rank correlation</th>
<th>P-value</th>
<th>High to Medium</th>
<th>Medium to Low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Budget</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2</td>
<td>Automobiles</td>
<td>0.888</td>
<td>0.18</td>
<td>0.001</td>
<td>☐</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>3</td>
<td>Ridership</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4</td>
<td>Carbon emission</td>
<td>0.056</td>
<td>0.18</td>
<td>0.743</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5</td>
<td>Ethanol Consumption</td>
<td>0.021</td>
<td>0.55</td>
<td>0.934</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>6</td>
<td>Gasoline consumption</td>
<td>0.056</td>
<td>0.43</td>
<td>0.778</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
</tr>
<tr>
<td>7</td>
<td>Transportation energy consumption</td>
<td>0.871</td>
<td>0.23</td>
<td>0.001</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
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</tbody>
</table>

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](image)

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 indicators. 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.

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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

Strictly as per the compliance and regulations of:
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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.
Table 1: Technical characteristics of dams considered for this study (DSI, 2016)

<table>
<thead>
<tr>
<th>#</th>
<th>Dam</th>
<th>Aim (*)</th>
<th>Height from river bed (m)</th>
<th>Completed Year</th>
<th>Type (**)</th>
<th>Volume of embankment (hm³)</th>
<th>Volume of reservoir (hm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alibey</td>
<td>D+F</td>
<td>28.0</td>
<td>1983</td>
<td>EF</td>
<td>1.927</td>
<td>65.00</td>
</tr>
<tr>
<td>2</td>
<td>Armagan</td>
<td>I</td>
<td>57.5</td>
<td>1999</td>
<td>RF</td>
<td>1.560</td>
<td>51.50</td>
</tr>
<tr>
<td>3</td>
<td>Atikhisar</td>
<td>I+D+F</td>
<td>33.7</td>
<td>1973</td>
<td>EF</td>
<td>2.218</td>
<td>52.20</td>
</tr>
<tr>
<td>4</td>
<td>Bakacak</td>
<td>I</td>
<td>50.0</td>
<td>1998</td>
<td>RF</td>
<td>2.200</td>
<td>139.00</td>
</tr>
<tr>
<td>5</td>
<td>Bayramdere</td>
<td>I+D</td>
<td>56.0</td>
<td>2011</td>
<td>RF</td>
<td>1.000</td>
<td>18.45</td>
</tr>
<tr>
<td>6</td>
<td>Buyukcekmece</td>
<td>D</td>
<td>10.1</td>
<td>1987</td>
<td>EF</td>
<td>1.718</td>
<td>172.45</td>
</tr>
<tr>
<td>7</td>
<td>Cokal</td>
<td>I+D</td>
<td>57.0</td>
<td>2011</td>
<td>CFR</td>
<td>3.500</td>
<td>204.00</td>
</tr>
<tr>
<td>8</td>
<td>Darik</td>
<td>D</td>
<td>73.0</td>
<td>1988</td>
<td>RF</td>
<td>1.600</td>
<td>107.00</td>
</tr>
<tr>
<td>9</td>
<td>Elmali II</td>
<td>D</td>
<td>42.5</td>
<td>1955</td>
<td>CG</td>
<td>0.103</td>
<td>10.31</td>
</tr>
<tr>
<td>10</td>
<td>Gokce</td>
<td>D</td>
<td>50.0</td>
<td>1989</td>
<td>RF+EF</td>
<td>0.133</td>
<td>21.71</td>
</tr>
<tr>
<td>11</td>
<td>Gokceada</td>
<td>I+D</td>
<td>33.0</td>
<td>1983</td>
<td>EF</td>
<td>0.560</td>
<td>16.80</td>
</tr>
<tr>
<td>12</td>
<td>Kadikoy</td>
<td>I+D+F</td>
<td>34.1</td>
<td>1973</td>
<td>EF</td>
<td>0.680</td>
<td>56.50</td>
</tr>
<tr>
<td>13</td>
<td>Kirazlicdere</td>
<td>D</td>
<td>109.0</td>
<td>1999</td>
<td>RF</td>
<td>5.200</td>
<td>60.00</td>
</tr>
<tr>
<td>14</td>
<td>Omerli</td>
<td>D</td>
<td>52.0</td>
<td>1972</td>
<td>EF</td>
<td>1.650</td>
<td>436.53</td>
</tr>
<tr>
<td>15</td>
<td>Sazlidere</td>
<td>D</td>
<td>23.0</td>
<td>1996</td>
<td>RF</td>
<td>1.780</td>
<td>131.50</td>
</tr>
<tr>
<td>16</td>
<td>Tasoluk</td>
<td>I</td>
<td>65.0</td>
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<td>RF</td>
<td>1.700</td>
<td>79.40</td>
</tr>
<tr>
<td>17</td>
<td>Tayfur</td>
<td>D</td>
<td>39.0</td>
<td>1985</td>
<td>RF</td>
<td>0.298</td>
<td>4.36</td>
</tr>
<tr>
<td>18</td>
<td>Umurbey</td>
<td>I</td>
<td>81.0</td>
<td>2003</td>
<td>EF</td>
<td>2.400</td>
<td>24.56</td>
</tr>
<tr>
<td>19</td>
<td>YeniceGonen</td>
<td>I+D+E+F</td>
<td>70.0</td>
<td>1997</td>
<td>RF+EF</td>
<td>2.400</td>
<td>227.04</td>
</tr>
</tbody>
</table>

(*) 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; Guilan & Kalkan, 2002; Kalkan & Guilan, 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-Ardebili 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. 1 also 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-Cekmec and Sazlidere 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)
Table 2: Results of seismic hazard analyses

<table>
<thead>
<tr>
<th>#</th>
<th>Dam</th>
<th>Deterministic Method *</th>
<th>Probabilistic Method **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M_{\text{max}}$</td>
<td>$R_{\text{max}}$(km)</td>
</tr>
<tr>
<td>1</td>
<td>Alibey</td>
<td>7.5</td>
<td>25.1</td>
</tr>
<tr>
<td>2</td>
<td>Armagan</td>
<td>6.5</td>
<td>121.1</td>
</tr>
<tr>
<td>3</td>
<td>Atikhisar</td>
<td>6.5</td>
<td>40.1</td>
</tr>
<tr>
<td>4</td>
<td>Bakacak</td>
<td>6.6</td>
<td>18.2</td>
</tr>
<tr>
<td>5</td>
<td>Bayramdere</td>
<td>6.2</td>
<td>26.4</td>
</tr>
<tr>
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<td>7.5</td>
<td>14.8</td>
</tr>
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<td>7</td>
<td>Cokal</td>
<td>6.3</td>
<td>2.7</td>
</tr>
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<td>8</td>
<td>Darlik</td>
<td>7.7</td>
<td>41.2</td>
</tr>
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<td>Elmali II</td>
<td>7.5</td>
<td>27.3</td>
</tr>
<tr>
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<td>Gokce</td>
<td>5.9</td>
<td>3.1</td>
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</tr>
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<td>Omerli</td>
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<td>34.6</td>
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<td>23.0</td>
</tr>
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<td>Tasoluk</td>
<td>5.6</td>
<td>1.8</td>
</tr>
<tr>
<td>17</td>
<td>Tayfur</td>
<td>6.3</td>
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</tr>
<tr>
<td>18</td>
<td>Umurbe</td>
<td>6.7</td>
<td>42.2</td>
</tr>
<tr>
<td>19</td>
<td>YeniceGonen</td>
<td>6.6</td>
<td>1.77</td>
</tr>
</tbody>
</table>

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, Kirazidere, 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

<table>
<thead>
<tr>
<th>#</th>
<th>Dam</th>
<th>Hazard Analysis</th>
<th>Total Risk (ICOLD, 1989)</th>
<th>Total Risk (Bureau, 2003)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class</td>
<td>Hazard Ratio</td>
<td>Risk factor</td>
</tr>
<tr>
<td>1</td>
<td>Alibey</td>
<td>III</td>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Armagan</td>
<td>I</td>
<td>Low</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Atikhisar</td>
<td>I</td>
<td>Low</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Bakacak</td>
<td>II</td>
<td>Moderate</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>Bayramdere</td>
<td>I</td>
<td>Low</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>Buyukçekmece</td>
<td>III</td>
<td>High</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Cokal</td>
<td>IV</td>
<td>Extreme</td>
<td>36</td>
</tr>
<tr>
<td>8</td>
<td>Darlik</td>
<td>II</td>
<td>Moderate</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Elmalı II</td>
<td>III</td>
<td>High</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>Gokce</td>
<td>IV</td>
<td>Extreme</td>
<td>34</td>
</tr>
<tr>
<td>11</td>
<td>Gokceada</td>
<td>II</td>
<td>Moderate</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>Kadikoy</td>
<td>II</td>
<td>Moderate</td>
<td>24</td>
</tr>
<tr>
<td>13</td>
<td>Kirazdere</td>
<td>IV</td>
<td>Extreme</td>
<td>34</td>
</tr>
<tr>
<td>14</td>
<td>Omerli</td>
<td>II</td>
<td>Moderate</td>
<td>36</td>
</tr>
<tr>
<td>15</td>
<td>Sazlidere</td>
<td>III</td>
<td>High</td>
<td>32</td>
</tr>
<tr>
<td>16</td>
<td>Tasoluk</td>
<td>IV</td>
<td>Extreme</td>
<td>34</td>
</tr>
<tr>
<td>17</td>
<td>Tayfur</td>
<td>II</td>
<td>Moderate</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>Ümurbey</td>
<td>I</td>
<td>Low</td>
<td>26</td>
</tr>
<tr>
<td>19</td>
<td>YeniceGonen</td>
<td>IV</td>
<td>Extreme</td>
<td>36</td>
</tr>
</tbody>
</table>

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, Elmalı-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 are 3.0H: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 of 150.8. 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 PSHA, the values of peak ground acceleration for OBE and MDE are 0.460g and 0.582g, 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 Canakale 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 impervious 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 0.225g and 0.306g, 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.
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 1.77 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).
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 Sazlidere), 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.

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Excitement 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)


Geometrical Characteristics of the Surfaces on Trapezium-Curved Plans

By Dr. V N Ivanov & Imomnazarov T.S

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

Strictly as per the compliance and regulations of:
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I. Introduction

The 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

\[ r_0(u) = x(u)i + y(u)j \]  

(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.

\[ r'_0 = s't; \quad s' = |r'_0|; \quad \tau' = s'k\nu = k_s\nu; \quad k_s = s'k; \quad \nu' = -k_s\tau. \]  

Then receive:

\[ \rho_u = (s' + v k_s)\tau + z_s k; \quad \rho_v = -\nu + z_v k. \]

Fig. 1: Pseudo-polar coordinate system
The coefficients of the first fundamental forms:

\[ E = (\rho_u, \rho_u) = (s' + vk'_s)^2 + zv^{'2}, \quad G = (\rho_v, \rho_v) = 1 + zv^{'2}, \quad F = (\rho_u, \rho_v) = z_u z_v. \] (5)

The unit normal vector of the surface

\[ m = \frac{1}{\Sigma} (\rho_u \times \rho_v) = \frac{1}{\Sigma} (z_u \mathbf{\tau} - (s' + vk'_s)(z_v \mathbf{v} + k)), \] (6)

\[ \Sigma = \sqrt{EG - F^2} = \sqrt{(s' + vk'_s)^2(1 + zv^{'2}) + z_u^2} \] is a discriminant of the surface.

The second derivatives of the equation:

\[ \rho_{uu} = (s'' + vk'_s)\mathbf{\tau} + (s' + vk'_s)k_s \mathbf{v} + z_{uu} \mathbf{k}; \quad \rho_{uv} = k_s \mathbf{v} + z_{uv} \mathbf{k}; \quad \rho_{vv} = z_{vv} \mathbf{k}. \] (7)

The coefficients of the second fundamental form:

\[ L = (\rho_{uu} m) = \frac{(s'' + vk'_s)z_u + (s' + vk'_s)^2 k_s z_v -(s' + vk'_s)z_{uu}}{\Sigma}; \]
\[ N = (\rho_{vv} m) = \frac{(s' + vk'_s)z_{vv}}{\Sigma}; \quad M = (\rho_{uv} m) = \frac{-z_u k_s - (s' + vk'_s)z_{uv}}{\Sigma}. \] (8)

The curvatures of the surface:

\[ k_u = \frac{L}{E} = \frac{(s'' + vk'_s)z_u + (s' + vk'_s)^2 k_s z_v -(s' + vk'_s)z_{uu}}{\Sigma (s' + vk'_s)^2 + z_v^2}; \]
\[ k_v = \frac{N}{G} = \frac{(s' + vk'_s)z_{vv}}{\Sigma (1 + z_v^2)}; \quad k_{uv} = \frac{M}{\sqrt{EG}} = \frac{-z_u k_s - (s' + vk'_s)z_{uv}}{\Sigma (s' + vk'_s)^2 + z_v^2 \sqrt{1 + z_v^{'2}}}. \] (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 \( (z_{v}=z_{uu}=0) \), there will be received the Monge’s surfaces:

\[ E = (s' + vk'_s)^2; \quad G = (\rho_v, \rho_v) = 1 + zv^{'2}; \quad F = 0; \quad \Sigma = (s' + vk'_s) \sqrt{1 + zv^{'2}}; \]
\[ L = \frac{(s' + vk'_s)k_s z_v}{\sqrt{1 + z_v^2}}; \quad N = \frac{z_{vv}}{\sqrt{1 + z_v^2}}; \quad M = 0; \]
\[ k_1 = \frac{k_s z_v}{(s' + vk'_s) \sqrt{1 + z_v^2}}; \quad k_2 = \frac{z_{vv}}{(1 + z_v^{'2})^{3/2}}. \] (10)
\[ z_v = \tan \theta; \quad z_{vv} = 0; \quad 1 + z_v^2 = \frac{1}{\cos^2 \theta}; \quad \Sigma = \frac{s' + vk_s}{\cos \theta}; \]

\[ E = \left(s' + vk_s\right)^2; \quad G = \frac{1}{\cos^2 \theta}; \quad L = \left(s' + vk_s\right)k_s \sin \theta; \quad N = 0; \quad k_1 = \frac{k_s z_v \sin \theta}{s' + vk_s}; \quad k_2 = 0. \quad (11) \]

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

\[ E = \left(s' + vk_s\right)^2; \quad G = 1; \quad L = N = 0; \quad k_1 = k_2 = 0. \quad (12) \]

**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 linear change of its amplitude:

\[ r_0(u) = X(u) \hat{i} + Y(u) \hat{j}; \quad X(u) = a \cos u; \quad Y(u) = b \sin u; \quad z(u, v) = c \frac{u}{2 \pi} \sin \frac{\pi v}{d}; \]

\[ u = 0 \div 2\pi; \quad v = 0 \div d, \]

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:

\[ s' = \sqrt{X'^2 + Y'^2} = a \sqrt{\eta}; \quad \eta = \sin^2 u + \varepsilon^2 \cos^2 u; \quad \varepsilon = \frac{b}{a}; \quad s'' = \frac{a \eta'}{2 \sqrt{\eta}}; \quad \eta' = \left(1 + \varepsilon^2\right) \sin 2u; \]

\[ k = \frac{X'Y'' - X''Y'}{s'^3} = \frac{\varepsilon}{a \eta^{3/2}}; \quad k_s = s'k = \frac{\varepsilon}{\sqrt{\eta}}; \quad k'_s = -\frac{\varepsilon}{\eta^2} \eta' = -\varepsilon \left(1 + \varepsilon^2\right) \frac{\sin 2u}{\eta^2}; \]

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

Coefficients of the fundamental forms:
\[
E = \left( a \sqrt{\eta + \frac{v \varepsilon}{\eta}} \right)^2 + \frac{c^2}{4\pi^2} \sin^2 \pi \frac{v}{d}, \quad G = 1 + \frac{c^2}{4\pi^2} u^2 \cos^2 \pi \frac{v}{d}, \quad F = \frac{c^2}{8\pi d} u \sin 2\pi \frac{v}{d},
\]
\[
\Sigma = \sqrt{ \left( a \sqrt{\eta + \frac{v \varepsilon}{\eta}} \right)^2 \left( 1 + \frac{c^2}{4\pi^2} u^2 \cos^2 \pi \frac{v}{d} \right) + \frac{c^2}{4\pi^2} \sin^2 \pi \frac{v}{d}.}
\]
\[
L = (\rho u m) = c \left( \frac{a^2}{2 \sin^2 u} + \frac{v}{\eta^2} \right) \sin 2u \sin \pi \frac{v}{d} + \left( a \sqrt{\eta + \frac{v \varepsilon}{\eta}} \right)^2 \frac{\varepsilon u}{d \mu} \frac{\cos \pi \frac{v}{d}}{2\Sigma};
\]
\[
N = -\frac{c\pi}{2d^2} \left( a \sqrt{\eta + \frac{v \varepsilon}{\eta}} \right) \sin \pi \frac{v}{d} \frac{\Sigma}{\Sigma}; \quad M = -c \frac{\varepsilon}{\pi} \frac{\sin \pi \frac{v}{d}}{d \mu} + \frac{1}{d} \left( a \sqrt{\eta + \frac{v \varepsilon}{\eta}} \right) \cos \pi \frac{v}{d}. \tag{12}
\]

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

\[
X(u) = a(\cos u + u \sin u); \quad Y(u) = a(\sin u - u \cos u) \quad \text{and generating sine} \quad z = b \sin \frac{v}{d}; \quad u = (1 + 5)\pi; \quad v = 0 \div d;
\]

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

\[ X(u) = aR(u)\cos u ; \quad Y(u) = aR(u)\sin u ; \]
\[ R(u) = \sqrt{2\cos 2u} , \quad u = (-1+1)\pi / 4 . \]
\[ s' = 2 \frac{a}{R(u)} ; \quad k = \frac{3 \frac{R(u)}{2}}{a} ; \quad k_s = 3 . \]

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

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

Let us consider the linear surfaces which aren’t surfaces of constant slope.

On fig. 5 there are shown wavy linear surfaces with different directrix curves.
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 b) $z(u, v) = v(c + d \sin tu)$, $t = p - \frac{\pi}{\Delta u}$, $\Delta u = u_k - u_n$ is a diapason of coordinate $v = (u_u \div u_v)$; $p$ is a number of half waves of oscillation of the generating straight line; $c = \tan \theta$, $\theta$ is an angle of the generating line, around which it made the oscillations:

\[
\begin{align*}
    a) & \quad z_u = -dt \sin tu; \quad z_{uu} = -dt^2 \cos tu; \quad z_v = c + d \cos tu; \quad z_{uv} = -dt \sin tu; \quad z_{vv} = 0; \\
    b) & \quad z_u = dt \cos tu; \quad z_{uu} = -dt^2 \sin tu; \quad z_v = c + d \sin tu; \quad z_{uv} = dt \cos tu; \quad z_{vv} = 0. 
\end{align*}
\]

(15)

Fig. 5: Wavy linear surfaces with different directrix:

- **a** – sine, **b** – hyperbola, **c** – parabola, **d** – cycloid, **e** – ellipse
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 \( N = 0, k_r = 0 \).

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:

\[
\begin{align*}
    s' &= 2a \sin (u / 2); \quad s'' = a \cos (u / 2); \quad k = \frac{1}{4a \sin (u / 2)}; \quad k_s = \frac{1}{2}; \quad k'_s = 0; \\
    E &= \left(2a \sin (u / 2) + \frac{v}{2}\right)^2 + (dv)^2 \cos^2 (tu); \quad G = 1 + (c + d \sin tu)^2; \quad F = -dv (c + d \sin tu) \sin tu; \\
    \Sigma &= \sqrt{\left(2a \sin (u / 2) + \frac{v}{2}\right)^2 + (dv)^2 \cos^2 (tu) \left[1 + (c + d \sin tu)^2\right] - \left[ dv (c + d \sin tu) \sin tu\right]^2}; \\
    L &= \left[adtv \cos^2 (u / 2) + \left(2a \sin (u / 2) + \frac{v}{2}\right) \frac{c + d \cos tu}{2} - \left(2a \sin (u / 2) + \frac{v}{2}\right) dv \cos tu \right] \frac{1}{\Sigma}; \\
    M &= \frac{dt}{2} \frac{(\sin tu - \cos tu) - 4a \sin (u / 2) \cos tu}{\Sigma}; \quad N = 0. \quad (15)
\end{align*}
\]

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 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 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]

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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 (Na2SiO3) solution were used as an alkaline solution with a mass ratio of Na2SiO3/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/mm², 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

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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$_2$SiO$_3$) solution were used as an alkaline solution with a mass ratio of Na$_2$SiO$_3$/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 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

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Size of burnt clay bricks (mm)</th>
<th>Area (mm²)</th>
<th>Load (KN)</th>
<th>Compressive strength (N / mm²)</th>
<th>Average compressive Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>112</td>
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</tr>
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<td></td>
<td>126</td>
<td>5.72</td>
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</tr>
<tr>
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<td>098</td>
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</tr>
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<td></td>
<td>126</td>
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<td>116</td>
<td>5.27</td>
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</tr>
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</table>

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

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Fly ash: GGBS</th>
<th>Average compressive strength (N / mm²)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>100 : 00</td>
<td>00.87</td>
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<tr>
<td>2</td>
<td>90 : 10</td>
<td>01.35</td>
</tr>
<tr>
<td>3</td>
<td>80 : 20</td>
<td>02.04</td>
</tr>
<tr>
<td>4</td>
<td>70 : 30</td>
<td>02.45</td>
</tr>
<tr>
<td>5</td>
<td>60 : 40</td>
<td>03.50</td>
</tr>
<tr>
<td>6</td>
<td>50 : 50</td>
<td>03.97</td>
</tr>
<tr>
<td>7</td>
<td>40 : 60</td>
<td>04.50</td>
</tr>
<tr>
<td>8</td>
<td>30 : 70</td>
<td>04.93</td>
</tr>
<tr>
<td>9</td>
<td>20 : 80</td>
<td>06.04</td>
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<tr>
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<td>10 : 90</td>
<td>06.60</td>
</tr>
<tr>
<td>11</td>
<td>0 : 100</td>
<td>07.45</td>
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**Table 3:** Water absorption test - Burnt clay bricks

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Dry weight (Kg)</th>
<th>Wet weight (Kg)</th>
<th>Water absorption (%)</th>
<th>Avg. water absorption (%)</th>
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</thead>
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<td>3.48</td>
<td>3.15</td>
<td>10.47</td>
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</tr>
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<td>3.40</td>
<td>3.12</td>
<td>08.97</td>
<td>9.69</td>
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<tr>
<td>4</td>
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<td>09.52</td>
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**Table 4:** Water absorption test - Geopolymer bricks (Fly ash: GGBS, 50:50)

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<tr>
<th>Sl. No</th>
<th>Dry weight (Kg)</th>
<th>Wet weight (Kg)</th>
<th>Water absorption (%)</th>
<th>Avg. water absorption (%)</th>
</tr>
</thead>
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<td>3.00</td>
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</tr>
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**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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Load (KN)</th>
<th>Size of brick (mm)</th>
<th>Area of brick (mm²)</th>
<th>Shear bond strength</th>
<th>Avg. shear bond strength (N/mm²)</th>
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<tbody>
<tr>
<td>1</td>
<td>2.80</td>
<td>(220 x 100 x 75)</td>
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<td>0.063</td>
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<td>2</td>
<td>3.00</td>
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</tr>
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<td>2.90</td>
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<td>5</td>
<td>2.79</td>
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Table 6: Triplet shear bond strength of Geopolymer bricks (Fly ash: GGBS, 50:50)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Load (KN)</th>
<th>Size of brick (mm)</th>
<th>Area of brick (mm²)</th>
<th>Shear bond strength</th>
<th>Avg. shear bond strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.8</td>
<td>(220 x 100 x 75)</td>
<td>22000</td>
<td>0.172</td>
<td>0.168</td>
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<td>3.7</td>
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</tr>
<tr>
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<td>3.6</td>
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<td></td>
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<tr>
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<td>3.7</td>
<td></td>
<td></td>
<td></td>
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<td>5</td>
<td>3.8</td>
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</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Load (KN)</th>
<th>Size of brick (mm)</th>
<th>Area of brick (mm²)</th>
<th>Shear bond strength</th>
<th>Avg. shear bond strength (N/mm²)</th>
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</thead>
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<tr>
<td>1</td>
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<td></td>
<td>0.120</td>
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</tr>
<tr>
<td>4</td>
<td>0.9</td>
<td></td>
<td></td>
<td>0.120</td>
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</tr>
<tr>
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<td>0.9</td>
<td></td>
<td></td>
<td>0.120</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Load (KN)</th>
<th>Size of brick (mm)</th>
<th>Area of brick (mm²)</th>
<th>Shear bond strength</th>
<th>Avg. shear bond strength (N/mm²)</th>
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<tbody>
<tr>
<td>1</td>
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<td>(220 x 100 x 75)</td>
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<td>0.217</td>
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<td>3.8</td>
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<td>0.222</td>
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</table>
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/mm²; 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.

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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.
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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.
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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.

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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.

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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.

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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.

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ASSOCIATE OF ENGINEERING RESEARCH COUNCIL

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.
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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.

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 Waldroff, M.S., AERC.

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

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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.

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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.

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

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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.
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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.

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- Illustrations
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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.

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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.

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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.
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.

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 Electronic 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.

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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 through 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:
- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- 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:
- Explain the value (significance) of the study.
- 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.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- 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

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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.

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