**CIVIL ENGINEERING**

[**HOME**](../CONTENTS.htm)

Author : **ANIL MODINPUROJU**

Title of the thesis : **FACILITY BASED RURAL ROAD NETWOR PLANNING**

**USING SPATIAL TECHNIQUES**

Guide : **Dr. C. S. R. K. PRASAD**

Degree : **Ph. D.**

Student ID No. : **701302**

ABSTRACT

Provision of good rural roads to meet the public facilities changes the characteristics of rural transport. Efficient rural transportation depends largely on a well-knit road network to provide accessibility and mobility in rural areas. Rural roads are primary infrastructure which provide essential access to rural population to various social facilities such as education, health, transportation and market facilities. Transportation planning in rural areas is highly complicated because of the multiple activities having non-specific interaction between any two places. Various models for planning of rural road network were developed by different research organizations, educational institutions, and consultants but in actual practice, they have not been of much help to implementing agencies (shrestha 2013). There is a need for the consolidation of the existing rural road network for maintenance and connectivity to the local community and enable economical transportation of goods and services to provide better livelihood opportunities as part of poverty reduction strategy.

One of the primary constraints in the development of rural infrastructure is the lack of sufficient funds in developing countries. Apart from the limited resources to build rural infrastructures (roads, water supply, electricity, telecommunication network) and public facilities, the lack of proper planning methodologies for development, improvement, and management of rural infrastructure is also a significant problem. Optimal use of available funds is a necessity and may help to develop and improve the present situation. Populations covered by a road link (Kumar and Kumar, 1999) can be taken as significant indicator to be considered to take into account the socio-economic benefits from the rural road links. The ii

other factors can be costs (construction costs and travel costs). However, these factors cannot be assessed precisely for rural areas. Hence, costs can be considered indirectly taking distances (construction cost) and the person-km (travel costs) (Kumar and Tilloston, 1985; Makarchi and Tilloston, 1991; Singh, 2010).

This study envisages consolidation of the existing Rural Road Network to improve its overall efficiency as a provider of transportation services for people, goods and services. The proposed methodology in this study, enables to determine rural hubs in the rural areas based on the facility index of the settlements. The Village Facility Index (VFI) is calculated by considering the desirable coverage distance. Spatial analysis is carried out in the study area to identify the Desirable Coverage Distance of the Facility (DCDF). VFI is the summation of all facility indices such as Educational Facility Index (EFI), Medical Facility Index (MFI), Transportation and Communication Facility Index (T&CFI) and Economic Activity Facility Index (EAFI).

The rural road network is generated by connecting the rural hubs by minimum travel time path in Geographical Information System (GIS). In the present study, travel time was measured from the field by travelling along the road using design vehicle. In a place where the terrain is not flat and the level difference between the two origin-destination points is very high, travel time was considered in both directions. In this study, since the terrain is plain and traffic volumes in both directions are more or less equal, the travel time in both direction is assumed to be same. The Minimum Spanning Tree (MST) of network is generated from the existing rural road network. MST represents the minimum connection level necessary for the rural accessibility of a specified coverage distance. In this study, MST of network is considered as the optimal road network of the study area.

Fund available for rural road construction/upgrade is usually a constraint in developing countries. Hence, the available resources should be effectively used. For this, a prioritisation method is necessary. Based on a realistic and practical criterion, the rural road links in the network are to be prioritised. The study explored the different rural road network models for prioritization of links for new construction and upgradation works. In this study, planning for prioritization of links is achieved by considering two parameters i.e. population and vulnerability of link. The model allows investigating the public resource allocation to attain minimum total cost with an investment budget constraint, intended to design the infrastructure by keeping total transportation costs to a minimum.

**CIVIL ENGINEERING**

Author : **ARUKALA SUCHITH REDDY**

Title of the thesis : **DEVELOPMENT OF A FRAMEWORK FOR**

**SUSTAINABLE BUILDING ASSESSMENT**

Guide : **Dr. P. RATHISH KUMAR**

Degree : **Ph. D.**

Student ID No. : **716105**

ABSTRACT

The human race is now facing a looming crisis of resource depletion and global warming. Population trends in recent years indicate rapid urbanization with more than half of the world’s population living in urban settings. This problem poses several challenges to the governing bodies including the pressing demand for providing amicable living conditions vis-à-vis housing, transportation, health, education and infrastructure facilities. A mismanaged, haphazard approach to population growing needs, lead to degradation of the environment and undoes the progress in sustainable development achieved so far. To facilitate living conditions with a minimal backlash on the limited resources, it is imperative to make a transition towards sustainable urban development.

The built environment was recognized as the largest contributor to changes in the environment. The construction, operation, and maintenance of buildings are estimated to account for approximately 40%–50% of all energy usage and emissions of GHG globally. There may be economic benefits from the investments in infrastructural projects, but they do cause more negative impacts on social and environmental issues. From the construction industry perspective, it is believed that sustainability should take into account the protection of a regional uniqueness incorporating localized architecture depending upon the local needs of the people despite their economic status. It is understood that the sustainability in construction industry refers to habitat comfort, the durability and service life of the structure, optimum utilization of resources, efficient utilization of energy, water, land, protection of the environment, and developing social integrity. Sustainable construction simply mean efficient use of natural resources, minimize negative impact on the ecology and improve the human satisfaction and quality of life. Sustainable urban development has to achieve three goals of sustainability viz., economic, social, and environmental in order to be well implemented.

Developing countries often face challenges and priorities that are different from those of advanced countries. These include, but are not limited to infrastructure and housing deficit, rapidly rising population, skill shortage, social inequity and relatively unstable political climate. To accomplish the need for sustainability, it is vital to understand the interrelationship between social needs, economic feasibility, and environmental impacts. The basic needs include food, clothing and shelter and above all, the ability to live at higher standards i.e., economical aspects. Therefore, promoting and incorporating sustainability is nothing but balancing the main three pillars, ecologically termed as sustainable development and this approach is known to be ‘Triple-Bottom-Line’ (TBL) approach.

To balance economic growth with sustainable development in the building sector, many countries around the world have come up with several building assessment tools to assess the building’s sustainability performance. A Sustainable building is designed to minimize the environmental impacts and optimize resource consumption during various stages of its life cycle, for instance, Leadership in Energy and Environment (LEED) in the US, Building Research Establishment Environmental Assessment Method (BREEAM) of the UK, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) of Japan, Green Rating for Integrated Habitat Assessment (GRIHA) of India, etc. Studies conducted in this field have indicated that these building assessment tools are based mainly on the environmental component of sustainability and that there is a necessity to include economic, social, institutional, technical and cultural factors in the assessment tools (Abdul-Rahman et al. 2016; Banani et al. 2016; Chang et al. 2013; Chen et al. 2017; Erdogan and Šaparauskas, 2019; Henriksson, 2010; Hussin et al. 2013; Magent et al. 2009; Todd et al. 2010; UNEP SBCI, 2010; Zarghami et al. 2018).

Most of the building assessment studies are oriented towards environmental indicator only (Abdul-Rahman et al. 2016; Chan and Chan, 2004; Ding, 2008; Giddings et al. 2002; Jamilus et al. 2013; Riffat et al. 2016; Vatalis et al. 2013; Waris et al. 2014). This indicates disregard to social and economic aspects of sustainability, which could further lead to ecological imbalance and thereby, miss the real goal of sustainable development, though, some of them focused on measuring sustainable performance considering one or more indicators (Kylili et al. 2016). It is significant to consider environmental, social, and economic dimensions (TBL approach) while assessing the building performance towards sustainability. However, the TBL approach has been claimed to distract and limit research, as not all local-level development issues are clearly either environmental, social, or economic (Alwaer et al. 2010a, 2010b; Anadon et al. 2016; Cancino et al. 2015; Chan and Chan, 2004; Kaya and Kahraman, 2014; Kulkarni et al. 2017; Liu and Lin, 2016; Mahmoudkelaye et al. 2017; Teplý et al. 2018). The criteria like energy efficiency, indoor air quality, water efficiency, water management, pollution, sustainable sites, human comfort, innovation, material efficiency, and renewable energy etc in most of the studies have assumed to orient towards only one or more indicators like environmental, cultural, institutional, socio-economic and political etc., and ignore the significance over other indicators. For example, the ‘pollution’ criteria considered under ‘Environmental’ indicator is presumed to be insignificant towards another indicator like social and economic indicators and evaluated the criteria measure towards sustainability. The interrelationship between indicators, criteria, and interdependency among criteria and indicators has been neglected. Few of them considered TBL approach but failed to incorporate the technological advances (Akizu-gardoki et al. 2018; Al-Jebouri e tal. 2017; Ghodoosi et al. 2018; Laedre et al. 2015; Patil et al. 2016) which have always been the cornerstone in mitigating the unavoidable side-effects of development and in surpassing the limits/constraints dictated by the other indicators of sustainability (Park et al. 2017). It was observed that it is imperative to incorporate the Technological indicator by rejuvenating ideas of reduce, reuse, recycle, renovate, and repair into implementable solutions. The holistic view under the main umbrella i.e. TBL along with Technological indicator will balance the construction eco-system for achieving sustainability. Thus, there arises a need to integrate Social, Environmental, Economic and Technological (SEET) indicators for assessing the sustainability of building construction. There exists a cultural, ethical and economic dissimilarity between the developed and developing countries to understand and implement the sustainability in the construction industry.

The present study is focused on implementation and adoption of sustainable principles in building industry, to monitor the performance and identify the specific indicators and criteria. It is noteworthy to observe here that, mere transfer of indicators and criteria from an existing building assessment framework developed for a particular country is not suitable to other country due to differences in regional, culture, heritage and geographical conditions of another country. The transfer of Technology can be successful only when current priorities and prevailing conditions of specific location are incorporated. Hence, the assessment tool developed for one nation or area may not be acceptable for another area. The present study aims at promoting, monitoring and evaluating sustainable building with regard to SEET indicators in order to achieve sustainable built environment for better quality of life.

Assessment of building performance requires suitable criteria and indicators and active participation of experts from various domains of construction industry to consider real-time conditions of a specific region. This involves multiple perceptions from decisionmakers considering multiple dimensions and criteria for achieving a single goal. For a framework to be well-developed, a reliable weighting structure has to be proposed to accept and institutionalize the importance of a wide variety of sustainable construction concerns. Most of these methods as said earlier are obstructed by components such as climatic circumstances, regional and geographic differences, culture, socio-economic elements. For this reason every nation/area needs their own strategical plan to assess whether the construction industry is implementing appropriate sustainability practices. The Analytical Hierarchy Process (AHP) method is a well-known Multi-Criteria Decision Making (MCDM) technique for determining the weights for any kind of hierarchical structure in various domains. However, it is not effective to handle the uncertainty and imprecision of the decision-maker. Fuzzy set theory on the other hand captures the vagueness, uncertainty, and impreciseness of the decision-maker.

From a detailed review of the literature, the following are the observations

A detailed literature review was carried on sustainable development with a focus on building assessment tool suitable to regional variations, climate conditions, culture, heritage and topographical conditions of developing countries like India, based on SEET aspects. The literature study was also aimed at emphasizing the adoption of existing tools for their suitability, similarities and differences and further checked for the possibility of adapting to the prevailing conditions without the need for life cycle inventory data. The following are the observations reported from the literature review:

1. There are studies reported on the factors influencing sustainable construction and that affect the building performance towards sustainability.
2. Most of the work reported the building performance considering the environmental dimension only. Some of them considered both environmental and economic dimensions to observe the impacts, burdens and cost implications.
3. There are very few studies reported on the building assessment based on TBL approach i.e., Social, Environmental and Economic dimension. However, these lack the interrelationship among the dimensions and it was noticed that the assessment tools developed for one nation or region might not be applicable to others.
4. It has been observed from the literature that, ‘Technological’ advances has always been the cornerstone in mitigating the unavoidable side-effects of development and in surpassing the limits/constraints dictated by the other indicators of sustainability vis-àvis Social, Economic and Environmental.
5. It was felt that it is imperative to incorporate the technological dimension by rejuvenating ideas like reuse, recycle, reduce, renew and regenerate into implementable solutions of the existing TBL to achieve complete sustainable construction SEET indicators.
6. Most of the assessment tools utilized the Analytical Hierarchy Process (AHP), a Multi- Criterion Decision Making (MCDM) method to assess the relative weight.
7. The concept of fuzzy logic was utilized to capture the ambiguity and vagueness of the decision-makers. It can also be inferred that the Delphi Technique (DT) is preferable to reach a consensus for the identified criteria based on previous studies.
8. It is important to decide the applicable criteria and sub-criteria to be compatible with the Indian context, which exhibits a wide range of climates, cultures, and topographic features. This would enable implementing a domestic assessment method for measuring building performance.
9. It was observed that due to the unavailability of appropriate life cycle inventory data for building materials in developing countries like India, the existing assessment tools (GRIHA, LEED, and IGBC) have disregarded the material component while evaluating the sustainable building performance. Hence, there is a need to study the behavior of material performance towards sustainability.
10. It was also felt that there is a necessity to develop a handy Graphical User Interface (GUI) system, a self-assessment tool to estimate the sustainable building performance.

The scope of the present study includes the following

* + Based on the available existing assessment tools, guidelines and policies, the criteria and attributes are identified considering regional context, climate conditions, culture, heritage, and topographical conditions.
  + Assigning and standardizing the relative weights for sustainable indicators, criteria and establish inter-relationship between them.
  + Distribute credit points to sustainable attributes corresponding to each criterion so as to quantify the building performance and thus generate a sustainable building performance score.
  + Assess the material performance towards sustainability by generating a material index considering material life-cycle phases.
  + Develop a Graphical User Interface (GUI) web portal using HTML, JavaScript and other tools and technologies to assess the building performance score and thus rate the building.

Based on the observations from the literature review, the following objectives are defined for the present investigation.

* + 1. To identify and evaluate relative weights of sustainable criteria and indicators (SEET) and establish Inter-relationship between them based on existing tools (LEED, BREEAM, GRIHA, and IGBC), guidelines and policies.
    2. To obtain the relevant quantifiable attributes and pre-requisites for each criterion and assign weights to them for assessing the building performance.
    3. To quantify the building material index by integrating sustainable SEET indicators, factors influencing material sustainable performance and material life-cycle phases, without the need for inventory data.
    4. To develop a sustainable building performance scoring system based on relative weights of criteria and global weights of sustainable attributes, and thus develop an automated GUI embedded Sustainable Building Assessment Tool (SBAT).

To achieve the above-mentioned objectives, a detailed program is designed and carried out in four different phases.

**Phase - I**

This phase is dealt in four stages: Comparing, identifying, evaluating relative weights and establishing interrelationship between indicators and criteria.

The significant criteria that can assess the sustainable performance of a building were identified based on the existing assessment tools (BREEAM, LEED, IGBC, and GRIHA), guidelines, policies and related publications considering local context, climatic conditions, culture, topography, and ethical aspects that prevail in developing countries like India. These criteria and sub-criteria are assessed and checked for the possibility of transfer and for adopting in the Indian context. Further, the identified criteria are refined and screened out using Delphi Technique (DT) and Relative Importance Index (RII) to reach a consensus on the diagnosed criteria their related attributes for quantification. Based on Six expert decision-makers belonging to categories such as Academicians, Engineers, Designers, Architects, Consultants, and Other Technocrats, the criteria whose value is more than or equal to 0.7 has been screened out for selecting the most significant attributes. A total of eight criteria and 37 attributes were established to evaluate and assess the building performance towards sustainability. For evaluating the relative weights of criteria and indicators, questionnaires were framed in such a way that the relative importance of criteria with respect to each indicator (SEET) is obtained on a seven point Likert scale. The consistency of the data is checked using Cronbach’s Alpha coefficient before performing statistical methods. In order to capture the ambiguity and vagueness of the respondents to the questionnaires, fuzzy logic is integrated with AHP and termed as FAHP, a Hybrid Multi-Criteria Decision Method (HMCDM) for assigning the relative weights to indicators and criteria. To perform FAHP, a number of pairwise comparisons for the four sustainable indicators and eight sustainable criteria for each respondent (Total 58) were performed. A total of 346 [4 x 4] matrices were developed to assign relative weights to sustainable indicators (SEET). Similarly, a total of 232 [8 x 8] matrices were developed to assign the relative weight to sustainable criteria. The interrelated weights are then obtained by multiplying the relative weights of sustainable indicators and criteria. From the interrelated weights of criteria and indicators, the average weight is obtained by pooling along with the criteria with regard to SEET indicators to identify significant criteria.

**Phase - II**

This phase of work intends to quantitatively assess the eight criteria which were identified in the previous phase with suitable attributes considering various pre-requisites. The approach involves determining the relative weights to sustainable attributes, assigning global weights to pre-requisites for developing a Sustainable Building scoring system using FAHP to develop a SBAT. Further, to assess the attribute performance, the relative weights of criteria and their corresponding attributes are multiplied to get the global weight. Based on the global weights of attributes, the pre-requisites were allotted with credit points in order to quantify the building performance on the practical field.

**Phase - III**

Based on the comprehensive literature review, guidelines and policies, and existing assessment tools, 10 key sustainable factors were identified which were most relevant to the material assessment. Three different approaches have been established based on MCDM methods to assess the material prioritization based on the identified sustainable factors. Each method has its own significance and justification in selecting a sustainable material alternative. The three methods include (i) Entropy-based Fuzzy Technique for Order Preference by Similarity to Ideal Solution (EFTOPSIS). (ii) Material Sustainable Performance Score (MSPS) and (iii) Sustainable Material Performance Index (SMPI). All the methods utilized the same input data set received from 54 respondents based on 10 sustainable factors and indicators for evaluation. In this phase, five different alternatives of binder material aiming at developing a sustainable concrete has been investigated based on different methods. The prominently used binder material alternatives considered were – Ordinary Portland Cement (OPC), Pozzolanic Portland Cement Flyash based (PPC-F), Pozzolanic Portland Cement Slag based (PPC-S), Geopolymer (GP) and Composite Cement (CC).

**Phase -IV**

This phase of work emphasizes on developing preference-based sustainable building score and an overall SBPS considering SEET indicators. To differentiate the building performance towards sustainability, based on Sustainable building Performance Score (SBPS), the study proposes five different performance levels to categorize the building performance. Graphic User Interface (GUI) is developed for lucidity in use of SBAT, utilizing open-source software and technologies (Tomcat Apache server, JavaScript, Java Server Pages, and HTML). The GUI includes the background page, a methodology page and, an Input & Out page. The input page consists of Yes/No and percentage type of questionnaire, while, the output page consists of pictorial representations of sustainable building performance. The GUI will act as a self-assessment tool. Further, a QR code is embedded in the HTML web portal for the assessment tool to improve awareness and public outreach. To spread the utility and enrich the convenience of using SBAT, the QR code is embedded in the link given below.

The study identified the need for promoting and practicing sustainable design and adoption of sustainable principles enabling the transformation from the conventional to sustainable construction in India. The following conclusions are drawn from the present research work.

1. A new Technological dimension has been incorporated in the existing Triple Bottom Line (TBL) approach by introducing the concept of 5R’s (Reduce, Recycle, Reuse, Renovate and Repair).
2. Eight criteria and 37 attributes have been tailored under Social, Environmental, Economic and Technological (SEET) indicators, to adapt to the Indian context considering climatic variations, local context, topography, culture, and heritage.
3. The Technological indicator with a normalized interrelated weight of 28.4% was highest among SEET indicators. Also, under the Technological indicator, the criterion ‘Material and Waste Management’ has attained the highest interrelated weight of 15.56%.
4. The relative weights of the criteria are obtained from the Eight focused expertise groups comprising of Academicians, Consultants, Contractors, Designers, Engineers, Architects, Suppliers and other stakeholders of the construction industry based on a structured questionnaire on a five-point Likert scale.
5. The eight proposed criteria include Water Efficiency (12.63%), Materials and Waste Management (13.96%), Health and Well-being (13.04%), Energy Efficiency (13.15%), Sustainable Sites (12.88%), Social Welfare (11.48%), Transportation (11.36%), and Management (11.49%). These criteria facilitate policymaking, formulate guidelines and develop the green building rating tool.
6. From the findings, it was observed that the relative weights of indicators are in the order of Environmental (30%), Technological (27%), Economic (22%), and Social (21%). Material and Waste management (MW) and Energy Efficiency (EE) attained the highest relative weights of 14.98% and 13.96% respectively.
7. The criteria, ‘Regionally available materials’ and ‘Renewable energy production’ attained global weights of 3.01% & 2.40% respectively among the various attributes chosen under technological indicator.
8. Ten significant factors viz., Climate change, Pollution, Construction & Demolition Waste, resource consumption, life cycle cost, Health & Safety, Local Economic Development, Recyclability and Reusability, Human Satisfaction, and Practicability & Flexibility were identified to assess the material performance based on content analysis.
9. Three methods (EFTOPSIS, MSPS, and SMPI) were used for assessing the material performance. These methods revealed the significance of adopting material life cycle phases in the selection of sustainable material, without the need for inventory data.
10. It was noted that the method ‘Sustainable Material Performance Index’ (SMPI) was found to be robust and flexible and was able to accommodate both qualitative and quantitative insights. Higher the SMPI value better is the material performance towards sustainability.
11. Among the five different binder material alternatives (OPC, PPC, PSC, GP, and CC) investigated, it was observed that Geopolymer (GP) is highly prioritized with an SMPI value of 10.63. This was evaluated based on MCDM methods.
12. The study witnessed the order of significance of the material life cycle as Postconstruction (39%), Construction (32%) and Pre-construction (29%), based on analysis of Relative Ranking Index (RRI).
13. Among the 10 identified sustainable factors for material evaluation, the factors ‘Climate change’ and ‘Pollution’ has highest SMPI values in the three life-cycle phases.
14. The SMPI framework developed from the study facilitates valuable inputs to building professionals in selecting a sustainable material alternative, without the need for Life Cycle Inventory data.
15. The novel method of assessment of building (SBAT) using attribute global weights takes into account the sensitivity to suit the practices, issues, and priorities of local to a certain region.
16. A scoring system to evaluate the Sustainable Building Performance Score (SPBS) based on the allotted credits points to attributes was developed. Further, a five-star rating based on a number of credit points to categorize sustainable performance of the building, more robust than the other building assessment tools are evolved.
17. A Graphical User Interface (GUI) embedded with QR code is developed for the enduser and acts as a self-assessment tool to identify the potential gaps and improvements for attaining the status of a sustainable building.

Through the development of the SBAT framework, a new contribution has been made to the literature for assessing the buildings. The most important of those are as follows:

* + The well-known existing assessment tools for building assessment tend to avoid explicit disclosure of the process based on which their methods are developed. This study not only proposes a theoretical model, but also, makes the methodology transparent.
  + The basis of any building assessment method is embedded in its assessment indicators, criteria, attributes and prerequisites. The present study has disclosed the applicable criteria and attributes that form the main structure specific to Indian sustainable building assessment.
  + Weighting systems are integral to reliable evaluation. This study has determined a weighting system for the approved criteria and attributes, which form the most applicable framework for the sustainability development of the built environment in India. The weighting system developed, includes a procedure (weights, interrelations, rating formulas, benchmarking expression and categorization) that provides a single result to indicate the level of sustainability of the built environment.
  + In terms of impact on the community, the framework can potentially act as an education medium that encourages a continuous learning process, enhances communication between, and participation of the stakeholders Viz., Architects, Designers, Consultants, Engineers, Contractors, Suppliers, and Academicians. The framework developed could potentially be used as a guideline for planning or policymaking to promote sustainable buildings in India. It is hoped that in this manner, the theoretical model becomes more flexible and consequently more adoptable, for other developing countries also.

More broadly, Sustainable Building Assessment Tool (SBAT) contributes to the development of a new model or approach appropriate to developing countries, through which a country-specific building sustainability assessment framework may be established.

**CIVIL ENGINEERING**

Author : **D. HARINDER**

Title of the thesis : **RUTTING POTENTIAL OF COIR GEOTEXTILES AS**

**INTERFACE OVER POOR SUBGRADE FOR LOW**

**VOLUME ROADS**

Guide : **Dr. S. SHANKAR**

Degree : **Ph. D.**

Student ID No. : **701405**

ABSTRACT

Low Volume Roads (LVRs) constitute an integral component of the road system in all countries. Their importance extends to all aspects of the social and economic development of rural communities. India has a total road network of over 5.3 million kilometers in length, making it the second-largest road network in the world. This is about 80 percent of all types of roads in India. Given this, they often form the most crucial link in terms of providing access to educational, medical, recreational and commercial activities in local and regional areas.

The use of geosynthetics for engineering applications is not a new concept. The concept of reinforcing weak soils to enhance their load carrying capacity has been developing until present times, and the first textiles were used in road construction in the United States in 1926. After that, it has been practiced for centuries in various infrastructure projects and road construction. Geosynthetic materials include geotextiles Geonets, Geogrids, Geocells, and Geocomposites. Most of these materials become a permanent part of the road. The use of Geosynthetic materials has grown significantly in road construction for the past 40 years and trial construction over the past 15 years. In the pavement, they perform four essential functions, namely reinforcement; separation; drainage; and filtration. Today a variety of geosynthetic materials can be used in many engineering projects such as roads, railroads, dams, retaining walls, tunnels, landfills, recreation areas, etc. The construction of LVRs on weak subgrade soil within the sinking budget is a challenging task. Most of these roads are lower order roads and subjected to low traffic. Under such circumstances whenever the poor native subgrade soil found, it is mandated to adopt the soil stabilization techniques or ground improvement methods.

Coastal and river portion of India is predominantly blessed with clays and expansive soils. These soils behave very typically due to the presence of montmorillonite minerals. Further, they pose several problems in terms of swelling and shrinkage and contribute cause for various distresses. To address these issues one of the common and innovative techniques are promoting the usage of geotextiles. So, the utilisation of geotextiles has gained universal promises to enhance the weak subgrade soil and geotechnical engineering aspects.

A review of existing literature revealed that most of the experimental studies were conducted on polymeric geosynthetic to reinforce the weak subgrade soil; limited research is available on coir Geotextile applications for LVRs. The LVRs are usually the lower order roads in the world, where the traffic ranges from 100 vehicles per day to 5000 vehicles per day.

The coir geotextile is naturally available eco-friendly and abundant material. It is available in huge quantity in the coastal area and also Malaysia, Indonesia, Srilanka, etc. The coir geotextile has higher tensile strength, more extended durability high performance among the other natural geotextile material, the utilisation of coir geotextile mats in pavement and geotechnical applications having high demand. It also creates an opportunity for rural employment, saving of natural material such as aggregate, morrum soil in the pavement application. With this background, in the present study four types of the coir geotextile mats such as Non-Woven Coir Mat (NWCM), Woven Coir Mats (WCM), Coir Composite (CC) and Geogrid with Non-Woven Coir Mat (GG+NWCM) combinations were considered with a aim to evaluate their effectiveness and potential benefits in laboratory using the Wheel Tracking Test (WTT) setup and in-situ by constructing a test tracks in the field under Accelerated Pavement Testing (APT). The primary conclusion from the laboratory study is that the maximum and minimum rut depth was 37.0 mm and 13.0 mm was found at sub-base-I and sub-base-II with 200mm thickness of the fabricated mould. The placement of the coir geotextile mats with morrum soil showed more significant performance in terms of rut depth and No. of passes than the gravel soil sub-base. It is also concluded that the inclusion of coir-geotextile mats improved the No. of passes (1200 passes) in sub-base-II with 100mm layer thickness with 300 mm assemble of mould during reduction thickness of the sub-base material. The rut depth at sub-base-I and sub-base-III position are noticed with reinforcement and without reinforcement as 3.0 mm, 4.0 mm and 11.0 mm, 24.0 mm respectively. In addition, the gravel sub-base soil is more effective when providing the decreased thickness of the sub-base as per the design standard charts (225 mm). In the case of the reinforcement function, the composite material provided better reinforcement than the woven and non woven coir mats. From the test track study, it was noticed that the reduction (55mm to 40mm) of the sub-base layer thickness is more in case of gravel soil with different types of coir geotextile. The deformation in the gravel sub-base soil is less than the morrum sub-base soil. To summarize finally, it is noticed that test track studies are more reliable to quantify the performance of these materials than laboratory evaluation. The coir composites material are shown the better function (reinforcement and separation) than the woven coir geotextile, the thickness of pavement can be reduced up to 55 mm with provisions of coir geotextile mats.

**Keywords:** Coir Composite, woven coir mat, non-woven coir mat, and geogrid with non wovencoir mat, wheel tracking test, accelerated pavement test, reinforcement, separation, rutting.

**CIVIL ENGINEERING**

Author : **D ABHIGNA**

Title of the thesis : **GAP ACCEPTANCE BEHAVIOUR AND CAPACITY**

**ANALYSIS OF URBAN UNCONTROLLED**

**INTERSECTIONS FOR MIXED TRAFFIC CONDITIONS**

Guide : **Dr. K. V. R. RAVISHANKAR**

Degree : **Ph. D.**

Student ID No. : **701401**

ABSTRACT

Intersections are the critical zones where vehicles perform different maneuvers in an attempt to share the same space at the same time. As the vehicle reaches the intersection, the driver of the subject vehicle has to take a quick decision by taking into account the intersection geometry, speed and type of the vehicles approaching the intersection from the other legs. At uncontrolled intersections there are no external signs or signals to control the movement of vehicles and the traffic operates based on the priority of traffic movements. In mixed traffic conditions priority rules are often violated by the road users. Vehicular interactions at uncontrolled intersections under mixed traffic conditions are very complex. At higher traffic volumes, the minor road vehicles tend to wait for longer time to cross the intersection that increases the probability of the vehicles to accept the shorter gaps. Hence, the general behavior of different vehicle types and the gap required for each vehicle type approaching from the minor and the major road taking right turn need to be carefully analyzed. Gap acceptance method is used for mixed traffic condition because it is based on the critical gap and follow-up time, which in turn depends on the type of vehicles and traffic conditions. Also, gap acceptance procedure is more suitable for mixed traffic conditions because it can be used for different composition of vehicles.

For this study, data was collected from three three-legged and three four-legged intersections located in various cities in India. The following parameters were extracted from the videographic data at each intersection and for each vehicle type: total volume, gap accepted, gap rejected, follow-up time, stopped delay, and total delay. This study tries to analyze the effect of vehicle type on gap acceptance behaviour of each of the right turning vehicles from the minor and the major road. Also, this study analyzes the major stream vehicle combinations on the gap-acceptance behavior of the minor stream and the major stream vehicles. It is observed that the size of the vehicles and traffic volumes has a significant influence on the critical gap. Depending on the major road vehicle combinations, the critical gap for each right turning subject vehicle varied from 1.4 s to 8.7 s.

Mixed traffic is composed of different vehicle types with varying geometric and acceleration characteristics. The performance of an intersection very much depends on the vehicular composition. This may be due to varying lengths and widths of different vehicle types which influences the intersection capacity. Different vehicle compositions are simulated using VISSIM for different vehicle types with an increment of 10% starting from 0% to 100%. The proportion of each vehicle type for the selected composition is considered in such a way that these proportions matches with the observed field proportion. Thereby, the effect of traffic composition on delay and volume at urban uncontrolled intersections is studied for all the vehicle types. Also, the total delay and the service delay is calculated for all the vehicles at all the intersections considered in this study. It is observed that there is an increase in delay as the size of the vehicle increases. Finally, the field delay data is compared with the simulated delay data and the error observed is less than 10% for all the vehicle types.

Capacity estimation is necessary for designing the intersection facilities and for upgradation of the control facilities to avoid unnecessary delay. Capacity at uncontrolled intersection is measured either by gap acceptance method, empirical regression approach, or conflict technique. Performance of uncontrolled intersection is influenced by the delay caused by low-priority movements on minor roads. In this study, capacity at uncontrolled intersections is estimated by considering the gap acceptance models including Tanner’s model, Drew's model, modified Sieogloch's model, and Luttenin's model. Further, the capacity is also estimated using the HCM (2010) and Indo-HCM methods. Based on the MAPE, Tanner's model is observed to be the best among the selected models for determining the capacity at urban uncontrolled intersections. Also, the performance of each of the six intersections is evaluated using the LOS criteria. HCM (2010) failed to differentiate between the performance of the six intersections. However, the LOS evaluated using the volume-capacity ratio resulted in significant variation in performance of the six intersections.

**Keywords** – Capacity, critical gap, follow-up time, gap acceptance, service delay, total delay, uncontrolled intersection.

**CIVIL ENGINEERING**

Author : **DANG DONG NGUYEN**

Title of the thesis : **THE IMPACT OF CLIMATE CHANGE ON**

**HYDROLOGICAL REGIMES IN THE SAIGONDONGNAI**

**RIVER BASIN**

Guide : **Dr. K.V. JAYAKUMAR**

Degree : **Ph. D.**

Student ID No. : **715014**

ABSTRACT

Extreme events are becoming more intense, more frequent and more destructive. Changes in extreme events such as flood and droughts are the primary ways that most people experience climate change. Flooding may intensify in many regions in the world particularly in regions of South Asia. Study for prediction of future flood risks in catchment scale using hydrological models along with climate change projection has played a considerable role in recent years.

Vietnam is one of the countries severely impacted by climate change. Trian watershed is located in the upper Saigon-Dongnai River basin and it is one of the biggest sub-basins of this river. Besides, this region is also the economic center in the south of Vietnam. However, not many studies have been conducted or reported in the literature to assess the impact of climate change on this region. It is, hence, necessary to evaluate the potential impact of climate change in future on this watershed, particularly on flood frequency, because flood events cause negative impacts on economic and social aspects.

Peak over Threshold (POT) approach uses the available flood data more efficiently and this approach can estimate return level more accurate. The Generalized Pareto Distribution (GPD) is fitted with POT magnitude as a default in extreme value analysis. However, there could be more than one distribution that can be fitted to the data sample. Therefore, it is important that POT approach for testing numerous distributions should be considered in assessing the changes of flood frequency.

The downscaled atmospheric data are used as input for a physically-based hydrological model to simulate future streamflow data. The changes in the frequency of flood peak extracted by the POT approach is compared between historical and future periods. The results indicate that there is a significant increase in flood magnitude under climate change for Trian catchment. To be more specific, the 100-year return level of Trian catchment is increasing up to 32.34 % in one of future scenario. Moreover, the results of this study also indicate that directly using the asymptotic distribution to model the POT dataset sometimes provides wrong insights.

The flood characteristics namely, peak, duration and volume for a given frequency provide important knowledge for the design of hydraulic structures, water resources planning, reservoir management and flood hazard mapping. Flood is a complex phenomenon defined by strongly correlated characteristics. If univariate frequency analysis is used to assess the behaviour of each flood characteristics, it will lead to over or under estimation of associated flood risk. In these cases, multivariate probability approach, which provides a comprehensive understanding of flood characteristics and their relationship, may provide better estimate of the flood magnitude when compared to the univariate approach.

Traditional multivariate parametric distributions have widely been applied for hydrological applications. However, this approach has some drawbacks such as the dependence structure between the variables, which depends on the marginal distributions or the flood variables have the same type of marginal distributions. Copulas are applied to overcome the restriction of classical multivariate flood frequency analysis by choosing the marginal distribution from different types of the probability distribution function for flood characteristics. The most important step in the modelling process using copula is the selection of copula function which is the best fit to data sample. The choice of copula may significantly impact on the bivariate quantiles.

From the results of the study, it is observed that the result from tail dependence test is useful in selecting the appropriate copula for modelling the joint dependence structure of flood variables. The extreme value copulas with upper tail dependence have proved that they are appropriate models for the dependence structure of the flood characteristics. Frank, Clayton and Gaussian copulas have been identified as the appropriate copula models in case of variables, which are diagnosed to have asymptotic independence.

Flood hazard mapping is one of the important aspects of flood risk assessment which has a significant implication on the planning of social and economic development activities. It also provides useful information to operate the flood warning system as well as to prepare the emergency evacuation plans. However, the development of the hydrodynamic models for the large river system is a very challenging task. The hydrodynamic models have to be large enough to cover the entire river basin and it must be sufficiently detailed to represent smaller features. Therefore, the latest advances in flood modelling techniques, such as flexible meshes generation and the advantages of coupled hydrodynamic model with the high-resolution of topography data will be applied in this study.

MIKE FLOOD, which is a coupled hydrodynamic model, is used to simulate the flood regime. The coupled hydrodynamic model has been developed for cross-sections based on channel modelling with 1D model and linking these floodplain modelling with 2D model. The design flood hydrograph is estimated using bivariate flood frequency analysis, high-quality topography data (i.e., DEM and LiDAR) and flexible meshes generation are used as the input data for hydrodynamic model to simulate the flood regime for the study area. Two parameters namely flood depth and flow velocity, which are obtained from a coupled hydrodynamic model, have been used for developing the high-resolution flood hazard maps.

This study presents the results of the assessment of the changes in the flood hazard and the duration of inundation under climate change context for Saigon-Dongnai River basin, Vietnam. From the results, it is observed that 54.47 km2 of the study area is subjected to H6 hazard index under 100-year return period in the present flood. 140.62 km2 and 50.90 km2 are under H6 hazard index for RCPs 4.5 and 8.5 scenarios respectively. This study indicated that the duration of inundation is not only controlled by flood magnitude but also by the volume of flood. Further, this study showed that most of the agricultural areas located downstream of Trian catchment will be severely inundated under climate change context.

**CIVIL ENGINEERING**

Author : **DASARI KARTHIK**

Title of the thesis : **A SCIENTIFIC APPROACH TO ESTIMATE THE**

**MASONRY LABOUR PRODUCTIVITY USING HUMAN**

**PHYSICAL PARAMETERS**

Guide : **Dr. C.B. KAMESWARA RAO**

Degree : **Ph. D.**

Student ID No. : **715001**

ABSTRACT

The productivity problems are usually associated with the performance of construction workers involved in labour-intensive tasks. The measurement of labour productivity at task level masonry activities is defined as a Masonry Labour Productivity (MLP). While low productive masonry worker practices were not challenged, the causes of low masonry labour performances at site level have not been focused. In construction projects, workers perform vigorous activities such as lifting and carrying construction material, pushing, dragging and pulling, loading, carrying out difficult work positions and engaged in tiresome activities. Accordingly, workers should be physically strong to withstand these vigorous activities on the construction field. Since different people have different physical strength capabilities, analysing physical ability-productivity relationships could propose a way to estimate labour productivity that can further aid in improving the productivity of construction industry.

It is observed that even though there is a vast research on productivity and significant factors responsible for variation of labour productivity, there is less focus towards the assessment of labour productivity based on the worker’s individual performance. The problem to be addressed in this research is the estimation of labour productivity, specifically in masonry construction with regard to physical capabilities, and how does these capabilities (i.e., human physical parameters) predict the task level labour productivity in masonry construction activities.

From the literature it is evident that utilization of human physical parameters in construction will help in determining the performance of the labour on site. The physical fitness of human body can be apparently assessed using isometric strength tests. These tests involve a maximum controlled contraction performed at a specified body joint angle of humans in stationary position. Therefore, to focus on effective application of human factors, present study selected four parameters such as age, Body Mass Index (BMI), Hand Grip Strength (HGS) and Upper Body Muscles Strength (UBMS) for measuring the labour performance on site.

In the present study, ongoing construction projects were selected in Warangal and Hyderabad of Telangana State, India. Survey was conducted on forty-five brick layers in which the data of thirty-eight workers is successfully recorded for the study. Therefore, the study is focussed on developing a scientific approach on a real time construction field for assessing labour productivity. The outcome of this research is expected to present a methodology that can be applied in construction industry.

Present research is specifically focused on masonry labour construction. An investigation on masonry workers in a real time building construction projects was carried out in India. Human parameters are denoted in the form of categories. The parameters are combined in to a unified parameter using human parametric categorization. Sum of the weightages of respective performance classes corresponding to human parametric category (can) of a worker will be the index of that worker which is termed as Human Parameter Index (HPI).

HPI is a non-dimensional and MLP is a dimensional parameter. MLP can be made in to non-dimensional parameter taking performance levels and physical abilities of labour in to consideration to form an indexed value, called as Productivity Index (PI). The HPI and PI of workers were calculated. From the relationship between HPI and PI of workers by regression analysis, a model to estimate MLP is developed.

The validity of the model was checked by conducting an independent survey. In a way it is proposed to apply the relationship model for a real time field construction activity and examine its level of prediction. Validation of model is carried out for workers involved in masonry construction activities. The newly developed parameter HPI is corroborated with the established heart rate parameter. It is found that as HPI increases heart rate of the workers decreased.

The influence of human parameters on MLP is examined in carrying out AAC block wall construction activity. All four human physical parameters together were found as good indicators in assessing MLP. The findings revealed that the subjects (masons) can be categorized with respect to human physical parameters based on their level of performance such as lower(ca3), middle(ca2) and upper(ca1) categories. Human physical parameters when considered in category showed promising trends on MLP.

The study contributes to knowledge about the utilization of parameters related to physical strength in qualitative assessment of MLP in construction industry. It is concluded that the productivity of construction labour on site can be assessed from categorizing their performance.

**CIVIL ENGINEERING**

Author : **HANUMA KASAGANI**

Title of the thesis : **A STUDY ON STRENGTH AND DEFORMATION OF**

**GRADED GLASS FIBER REINFORCED CONCRETE**

**UNDER UNIAXIAL STRESS**

Guide : **Dr. C.B. KAMESWARA RAO**

Degree : **Ph. D.**

Student ID No. : **714104**

ABSTRACT

Concrete is a brittle material, with low tensile strength and strain capacity. However, the tensile behaviour of concrete can be significantly improved by addition of fibers. Glass fibers are fundamentally different and their strength in tension is significantly higher than that of the host matrix. The fine size of the fibers also allows large volume fractions to be easily mixed and uniformly dispersed in the matrix. Closely spaced fibers can then provide effective reinforcing at the micro-cracking level, prevent the coalescence of micro-cracks into unstable macro-cracks, and increase the strength.

In most cases, fiber reinforced concrete (FRC) contains only one type of fiber. A given type of fiber can be effective only in a limited range of strength gain, ductility and toughness. FRC mainly dependent on the fiber properties and dimensions of the fibers. The combination of one type of fiber with another type of fiber or one length of fiber with another length of fiber, is commonly known as hybrid fiber reinforced concrete (HFRC). In hybrid fiber reinforced concrete, different fibers such as steel, glass and polypropylene etc. are combinedly used as fibers and it improves pre peak strength and post peak toughness by properly dispersing fibers.

Hybrid fiber reinforced concrete is a research area in which different types of fibers are combined where the best qualities of each contribute to improve strength and deformation of concrete. Short length and long length fibers are also combined to achieve the same benefits of hybrid reinforced concrete. Combining short length and long length fibers in concrete is named as Graded fiber reinforced concrete. Earlier research shows that short length fibres primarily control the propagation of micro cracks, and improve the ultimate strength whereas, long length fibers arrest the macro cracks and improve the post peak deformation of concrete. Thus different combinations of short and long length fibers would help in arresting the micro as well as macro cracks to improve both pre and post peak performances of concrete. Synergy between Short fiber-long fiber hybridization is realised but not investigated at length.

The present research work is carried out in two phases and are explained briefly. The first phase of investigation is aimed to understand the behaviour of Mono Glass Fiber Reinforced Concrete (MGFRC). The main variables of this study are length of fiber and volume fraction. Four different fiber lengths 3mm, 6mm, 12mm and 20mm and five different volume fractions 0.1%, 0.2%, 0.3%, 0.4% and 0.5% are used to study. This work is carried out with the two grades of concrete (M30 and M50).

The second phase of study is aimed to understand the behaviour of Graded Glass Fiber Reinforced Concrete (GGFRC). Two or more length of fibers are mixed to form Graded Fibers. When the mixture consists of 3mm and 6mm is named as Short Graded Fiber (SGF), mixture consists of 12mm and 20mm is named as Long Graded Fiber (LGF) and mixture of all the four lengths 3mm, 6mm, 12mm and 20mm is named as Combined Graded Fiber (CGF). The main variables of this study is short graded fibers (3mm+6mm), long graded fibers (12mm+20mm), combined graded fibers (3mm+6mm+12mm+20mm) and total volume fraction (0.3%, 0.4% and 0.5%). In this study mixing of fibers is done in proportion of 20%+80%, 40%+60%, 50%+50%, 60%+40% and 80%+20% to obtain graded fibers. This work is carried out with the two grades of concrete (M30 and M50).

**Phase-I: Study on Mono Glass Fiber Reinforced Concrete (MGFRC)**

In this investigation, the experimental work was carried out under uniaxial tension and uniaxial compression for M30 and M50 grade of concrete with the 0.1%, 0.2%, 0.3%, 0.4% and 0.50% fiber volume of Mono Glass Fibers (3mm, 6 mm, 12 mm and 20 mm length fiber). In order to understand the workability of Mono Glass Fiber Reinforced Concrete (MGFRC) the slump test was conducted. As volume of fiber and length of fiber increased from 0.1% to 0.5% the slump decreased. However, 0.4% and 0.5% volume of fibers led to bundling, balling and hence significant reduction in workability is observed in composite. Hence, Workability of MGFRC decreased with increase in fiber length and volume fraction. The specimens with 0.3% fiber volume content has shown the maximum improvement in compressive strength.

The tensile and compressive stress strain curves are analysed to obtain the initial slope, strengthening factor, ductility factor, strain hardening slope and Strain softening slope of the composite. Specimens with long length fibers (12mm and 20mm) exhibited higher ductility factor, energy absorption capacity than that of short length fibers (3mm and 6mm). Specimens with short length fibers showed higher strengthening and initial slope compared to the long length fibers.

Specimens with Short length fibers (3mm and 6mm) have given higher tensile strength than the specimens with Long length fibers (12mm and 20mm). Specimens with long length fibers (12mm and 20mm) have contributed more post crack deformation capacity than the specimens with short length fibers (3mm and 6 mm) in tension. Specimens with Short length fibers (3mm and 6mm) have given higher peak strength than the specimens with long length fibers (12mm and 20mm). Specimens with long length fibers (12mm and 20mm) have contributed more post peak deformation capacity than the specimens with short length fibers (3mm and 6 mm) in compression. Hence, the short fibers are more effective in improving the strength by delaying the formation of micro cracks and long fibers are more effective in increasing the deformations by bridging the macro cracks in both tension and compression.

Tensile properties of fibre concrete are governed mainly by the number, dispersion and orientation of fibres in the cracking area, as well as dispersion characteristics of fibres. Several techniques (Yang Y, 2002; Yilmaz Akkaya et al, 2001 and Bang Yeon Lee, 2009) including image analysis, transmission X-ray photography, and Advanced CCD Imaging Spectrometer (ACIS) are available for evaluating the fibre distribution in a composite made of cement matrix and steel, carbon, glass, or organic fibres; i.e., these techniques can be employed to determine the degree of fibre dispersion and orientation in the composite. Among these techniques, image analysis is the most applicable and trusted method to evaluate the distribution characteristics of fibres in a composite.

Fiber dispersion and fiber orientation at fracture plane of specimens is examined through optical microscope. The strength of the fiber reinforced composite is influenced by the fiber length coefficient (ηl), fiber orientation coefficient (ηθ) and fiber dispersion coefficient (ηd). Higher the fiber dispersion coefficient and fiber orientation coefficient higher the strength of composite due to homogeneity of fiber dispersion and fibers performs efficiently across the fracture plane.

Normal compressive stress generates transverse tensile strain. As the compressive stress reaches peak stress, dilation of concrete initiates and lateral deformation increases. Presence of fibers restrain the lateral deformation. Degree of resistance offered to lateral deformation is proportional to volume of fibers and the fibers come into action after cracking in concrete in compression which is similar to the action of fibers in concrete after the onset of cracking in tension. The fibers present in concrete will participate by resisting dilation of concrete only after sufficient mobilization of dilation of concrete. That is why there is a remarkable improvement in strain softening of concrete in compression with the increase in fiber content.

Strain softening in compression and strain hardening in tension is noticed. Irrespective of length of fiber, specimens with 0.3%, 0.4% and 0.5% have exhibited strain hardening in tension and corresponding strain softening is noticed in compression. It is noted that strain hardening in tension is not observed for specimens with 0.1% and 0.2% and corresponding strain softening in compression is not significantly present. The amount of deformation and slope in the strain hardening and strain softening region are directly influenced by the volume of fiber and length of fiber. In order to understand the complementary behaviour of strain hardening behaviour in tension and strain softening behaviour in compression, the normalised stress and normalised strain at the onset of strain hardening and at the inflection point of strain softening is taken for a given fiber length (Lf) and volume of the fiber (Vf).

Reinforcing index (RIMF) is defined as product of volume fraction (Vf) and aspect ratio of fiber (Lf/Df). Tensile and compressive stress strain behaviour is predicted for different reinforcing indexes. In order to correlate tensile and compression data for various Reinforcing Index (RIMF = Vf (Lf/Df)) of MGFRC, a relationship between Reinforcing Index and strain hardening in tension, strain softening in compression is proposed. Specimens with Short fibers i.e. RIMF of 0.64 and 1.29 producing low strain hardening in tension and strain softening behaviour in compression, where as in specimens with long fibers i.e., RIMF of 2.57 and 4.29 exhibited significant strain hardening in tension and strain softening behaviour in compression. As the reinforcing index (RIMF) of mono fibers increases the strain hardening in tension complements strain softening in compression.

A model is developed for predicting stress–strain curves of MFRC in tension and compression. All properties required for the generation of compressive stress-strain curves are estimated using the reinforcing index (RIMF). A material parameter β is developed for predicting stress–strain curves of MGFRC. The analytical curves show good correlation with experimental test results of MGFRC in both tension and compression.

**Phase-II: Study on Graded Glass Fiber Reinforced Concrete (GGFRC)**

In this investigation combination of different lengths of mono fibers are considered and named as Graded fiber reinforced concrete to distinguish from Hybrid fiber reinforced concrete. Inspiration is obtained from concrete mix proportioning where in different sizes of aggregates are combined to obtain well graded aggregates. Similar synergy with well Graded fibers of different lengths may improve strength and deformation of concrete. In the present work four lengths of AR glass fibers 3mm, 6mm, 12mm and 20mm are combined in different proportions to form Graded Glass Fibers.

MGFRC results shows that the given length of fiber can be effective only in a limited range of strength gain, ductility and energy absorption. To further improve the properties (strength and ductility) of the composite simultaneously different lengths of fibers are mixed together with different fiber volume combinations and named as Graded Fibers. In this investigation, two or more length of fibers are mixed to form Graded Fibers. When the mixture consists of 3mm and 6mm is named as Short Graded Fiber (SGF), mixture consists of 12mm and 20mm is named as Long Graded Fiber (LGF) and mixture of all the four lengths 3mm, 6mm, 12mm and 20mm is named as Combined Graded Fiber (CGF). In this present work, an attempt has been made to study the effect of addition of Graded Glass Fibers with different fiber length and volume fraction in Glass Fiber Reinforced Concrete. The experimental work was carried out under uniaxial tension and uniaxial compression for M30 and M50 grade of concrete with the 0.3%, 0.4% and 0.50% total fiber volume of SGF, LGF and CGF.

In order to understand the workability of graded fibers, slump test was conducted for M30-GGFRC and M50-GGFRC with 0.3%, 0.4% and 0.5% volume fraction. It can be concluded that, there is significant difference existed in the loss of the slump for mono glass fibers. The slump loss was small in the concrete with graded fibers. Hence, graded fibers improves workability.

Compression test was conducted on cube specimens of M30-GGFRC and M50-GGFRC with 0.3%, 0.4% and 0.5% volume fraction. Results shows that different fiber volume combinations of SGF mixes showed that cube compressive strength of SGF with 40%3mm+60%6mm is greater than all other short graded fibers whereas in LGF mixes showed LGF with 40%12mm+60%20mm is greater than all other long graded fibers and in case of CGF mixes showed that cube compressive strength of CGF with 40%SGF+60%LGF is greater than all other combined graded fibers. In any given volume fraction (0.3%, 0.4% and 0.5%), among all the mixes shows that CGF have given the best improvement in terms of cube compressive strength compared to MGF, SGF and LGF. It can be concluded that the combined graded fibers (CGF) improves the cube compressive strength of concrete.

In order to understand the tensile and compressive stress strain behaviour of Graded fibers (SGF, LGF and CGF). Uniaxial tensile and uniaxial compression test was conducted on dog-bone and prism specimens of M30-GGFRC and M50-GGFRC with volume fractions of 0.3%, 0.4% and 0.5%. Irrespective of volume of fibers i.e., 0.3%, 0.4% or 0.5%, the specimens containing the 40%3mm + 60%6mm of SGF has given the best benefit of improvement in both strength and deformation compared to all other short graded fibers and specimens containing the 40% 12mm + 60% 20mm of LGF has given the best benefit of improvement in both strength and deformation compared to all other long graded fibers. Specimens containing the 40% SGF + 60% LGF of CGF has given the best benefit of improvement in both strength and deformation compared to all other combined graded fibers.

Short graded fibers are more effective in improving the ultimate strength by delaying the formation of micro cracks and long graded fibers are more effective in increasing the deformations by bridging the macro cracks. The combination of short graded and long graded fibers forms the combined graded fibers. It can be concluded that the combined graded fibers (CGF) has given the best benefit performance in terms of strength and deformation compared to SGF and LGF. Irrespective of volume of fibers i.e., 0.3%, 0.4% or 0.5%, different lengths of fibers have controlled the different levels of cracking thus contributing to increases in strength and deformation of Graded Glass Fiber Reinforced Concrete.

In all, irrespective of volume of the fiber (0.3%, 0.4% and 0.5%) and grade of concrete (M30 and M50), long graded fibers (LGF) exhibited higher ductility factor, energy absorption capacity than that of short graded fibers (SGF). Short graded fibers showed higher strengthening and initial slope compared to the long length fibers. Hence, the combination of SGF and LGF i.e., CGF have exhibited the higher strengthening factor, ductility factor and energy absorption capacity than that of SGF, LGF and MGF in both tension and compression.

Fiber dispersion and orientation are the two important parameters to understand the tensile behaviour of the composite. These parameters are examined on fracture plane of M30-GGFRC and M50-GGFRC specimens with 0.3%, 0.4% and 0.5% volume fraction. It shows that the composite with SGF has more the fiber density at the center and less at the edges and corners. Where as in long graded fibers, the fiber density is more at the edges and corners and less at the center. Composite with CGF (containing SGF + LGF) showed the almost uniform distribution. The results of image analysis shows that graded fibers with different fiber volume combinations disperse homogeneously avoiding clumping or balling. Graded fibers showed the higher fiber dispersion coefficient and higher fiber orientation coefficient when compared to the mono fibers.

An equation is proposed to arrive at RIGF for graded fibers. This is developed on observing of stress strain behaviour and fiber density variations of GGFRC with different fiber volume combinations. The composite tensile strength and corresponding composite tensile strain of GGFRC is calculated based on the RIGF. The predicted composite tensile strength and composite tensile strain values are closer to the experimental values. A model is proposed to predict the tensile and compressive stress strain behaviour. All properties required for the generation of stress–strain curves are estimated using the reinforcing index (RIGF). A model is developed for predicting compressive stress–strain curves of MGFRC and GGFRC. The analytical curves show good correlation with experimental test results.

The strain hardening in tension and strain softening in compression phenomena is noticed in the stress strain behaviour of GGFRC which is similar to that of MGFRC. Degree of resistance offered to lateral deformation is proportional to grading of fibers (SGF, LGF and CGF) and volume of fibers (0.3%, 0.4% and 0.5%), and the fibers come into action after cracking in concrete in compression which is similar to the action of fibers in concrete after the onset of cracking in tension. With well grading of fibers, the strain hardening in tension complements strain softening in compression.

In order to understand the strain hardening behaviour in tension and strain softening behaviour in compression for M30-GGFRC and M50-GGFRC, a relationship between Reinforcing Index (RIGF) and strain hardening in tension, strain softening in compression is proposed.

The gradient of increase of strain hardening in tension is similar to the gradient of strain softening in compression for the specimen with the same RIGF and it is influenced by RIGF. It was observed as the value of RIGF decreased, the strain softening in compression increased and also increase in strain hardening in tension.

**CIVIL ENGINEERING**

Author : **JEW DAS**

Title of the thesis : **HYDROLOGICAL MODELLING AND UNCERTAINTY**

**ANALYSIS TO ASSESS THE IMPACT OF CLIMATE**

**CHANGE OF A RIVER BASIN**

Guide : **Dr. N. V. UMAMAHESH**

Degree : **Ph. D.**

Student ID No. : **701332**

ABSTRACT

Climate change is a global phenomenon having varying degree of regional impacts. Though there are different schools of thought regarding the contribution of different driving forces of climate like greenhouse gases, aerosols etc., and also the sequence and pace of the phenomenon, climate change and global warming is a reality. In the context of climate change, assessment of adverse effects on water resources for proper allocation and risk management has become a challenge for the research community. Changing nature of the climate, due to the perturbations induced by the human activities, draws significant attention in water resources and hydrology. To assess the induced impact in future for better risk and resources management, Global Climate Models (GCMs) are used as most credible tools. The climate variables are well simulated by GCMs at a coarser resolution i.e. at continental and hemispherical scale; however, the impact analysis at finer grid i.e. at regional scale requires the variables at the sub-grid scale. Due to the existing gaps between the GCM realizations and hydrological concern in spatial as well as temporal scale, the efficiency of the GCM to simulate at fine resolution decreases; whereas, the importance of the hydrological processes increases at finer scale. The method of modelling the hydrologic variables at a regional scale based on large scale GCM outputs is known as downscaling. The downscaling techniques are classified as statistical and dynamic; whereas, statistical downscaling has gained popularity in the hydrological studies because of its less computational time. Moreover, encompassing the uncertainty analysis with the future projection will improve the predictability and robustness of real-time prediction.

This thesis deals with developing statistical downscaling models to assess the climate change impact on river basin scale, uncertainty analysis associated with the multi-model GCMs and return levels with different return periods, comparison of uncertainty with stationary and non-stationary approaches, and spatio-temporal variation of water balance components with probability based areal drought analysis.

Initial part of the thesis is devoted to develop statistical downscaling model to predict monsoon precipitation over Godavari River basin from GCM output of large scale mean sea level pressure, specific humidity, and 500 hPa geopotential height. The historical data of the selected GCM outputs are obtained from the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) reanalysis project. Initially, two different climate models (Canadian Earth System Model, CanESM2; The Norwegian Earth System Model, NorESM1-M) with one future projected scenario and the later considers single model with different climate scenarios. The observed high resolution 1o × 1o gridded rainfall data over Godavari river basin are collected from India Meteorological Department (IMD) and the basin covers 25 IMD grid points. The downscaling model comprises of Principal Component Analysis (PCA), Fuzzy clustering, and multiple linear regression. PCA is used to reduce the dimensionality and correlation among the predictors. Also, fuzzy clustering is used to classify the principal components (PCs). Then, a statistical relationship is established between the PCs with membership functions and predictand (monsoon rainfall) to project the monsoon rainfall for the future over the 25 IMD grid points. With RCP 4.5 and two different climate models, it is observed an increasing trend of monsoon precipitation over the basin considering the collective effect of two models. However, the individual model projections are different from each other. CanESM2 model with RCP 2.6, 4.5 and 8.5 is considered to project the monsoon precipitation over the basin. In addition, a post modeling bias correction is introduced to minimize the error in the prediction through equiprobability transformation. From the statistical downscaling results, it is observed an increasing trend over the zone under high magnitude of rainfall in historical period and a decreasing trend over the zone under low magnitude rainfall in the past. Interannual variability of anomaly for sub-basins under the monsoon zone shows the frequency of deficit rainfall is very less in all the scenarios. A sudden increase in the precipitation is observed at different temporal scales in RCP 2.6 and 4.5; whereas a gradual increase in the rainfall for RCP 8.5.

In the second part, classification and regression based statistical downscaling is used to project the monthly monsoon streamflow over Wainganga basin, India using 40 large-scale global climate models (GCM) outputs and Representative Concentration pathways (RCP) scenarios. Mean sea level pressure, specific humidity, 500 hpa geopotential height, and 2m surface air temperature are used as potential predictors. Two machine learning techniques namely, support vector machine (SVM) and relevance vector machine (RVM) are considered to perform the downscaling. Both the techniques are calibrated and validated based on the historical observations and different statistical measures. RVM is able to obtain the better model efficiency than SVM and used to simulate the future projection of monsoon flows for different time periods (2011-2040, 2041-2070, 2071-2100) incorporating the GCMs‘ output. Ensemble average is obtained from the different individual GCM projections and considered to analyse the potential climate change impact. In addition, variability in water availability of the basin is examined by plotting the flow duration curve (FDC) for different scenarios and the associated uncertainty is analysed using non-parametric bootstrapping technique. Furthermore, the change point detection is performed using Bayesian analysis for the annual monsoon flows. It is observed from the obtained results that the upper extreme of the monsoon flows are highly sensitive to the increase in temperature and showing a continuous decreasing trend. The medium and low flows are increased in the future projection for all the scenarios and high uncertainty is noticed in case of low flows, particularly 0.8 probability of exceedance. Early detection of change point is detected in case of high emission scenarios (RCP 4.5, 6.0 and 8.5); whereas, in case of RCP2.6 the year of CP is detected later part of the twenty first century i.e. around 2070.

In the context of climate change, it is essential to quantify the uncertainty for better design and risk management practices. Therefore quantification the model and parameter uncertainties over a river basin are carried out. Six high-resolution Global Climate Models (GCMs) under the COordinated Regional Downscaling EXperiment (CORDEX) for the South Asia from the Indian Institute of Tropical Meteorology, Pune (IITM) with two Representative Concentration Pathways (RCPs) are used to access the future climate change impact on streamflow of Wainganga River basin. Uncertainty associated with the use of high-resolution multi-model is treated with Reliability Ensemble Average (REA) with bias-correction for rainfall and the bias-corrected weighted outputs are used as an input to Variable Infiltration Capacity (VIC) model, a physically based hydrological model. Multiple calibrations and validations are carried out for the hydrological modelling and the sensitive parameters of VIC are fixed through trial and error method. The parameter uncertainty associated with the future projected flows are dealt with the Bayesian analysis and modelled through Markov Chain Monte Carlo (MCMC) simulation technique using Metropolis-Hastings algorithm with the non-informative prior distribution of the parameters. It is found that the uncertainty in the high return period is more in comparison with the shorter duration with higher uncertainty in the RCP 8.5 than RCP 4.5.

In the prevailing adverse consequences of climate change, quantification of uncertainty and implementation of non-stationarity to model the return levels has gained popularity with the advancement of the computational facility. The potential impact of climate change on hydrological components which intensifies the uncertainties in the management of water resources are to be analysed. Therefore, in the present study future changes in the streamflow are analysed with non-stationary approach over Wainganga river basin, India. With the recent development of Extreme Value Theory (EVT), the annual maximum flows for past and future are modelled with non-stationary assumption and validated using Akaike Information Criterion (AIC) value and likelihood ratio test. Stationarity assumption fits well in the case of observed and future projected flows under RCP 4.5 whereas; non-stationarity is more suitable under high emission scenario like RCP8.5. The obtained future flood quantiles are not likely to be critical in the coming century under both stationary and non-stationary assumptions. The return level uncertainty bound is more in the case of high climatic forcing. The early changes in the estimated return levels under non-stationary approach are detected for the lower return period in comparison with the stationary method. In the case of annual maximum flood non-stationary estimate is more useful in lower return levels to design low capacity hydraulic structures. Bayesian uncertainty using Markov Chain Monte Carlo (MCMC) simulation provides high uncertainty range in the case of non-stationary assumption as compared to stationary assumption.

Water availability and streamflow are very sensitive to the change in the precipitation and temperature and evaluating the changes with respect to the climate change scenarios over a river basin will help in proper planning and management of the water resources systems. In order to address the climate change impacts on water balance components over Wainganga River basin, India, a macro scale, semi-distributed three layer variable infiltration model (VIC-3L) is applied as discussed earlier. The future projections (2020-2094) of the streamflow are analysed temporally and spatially over the basin. A probabilistic based drought event using standardized precipitation evapotranspiration index (SPEI) and also the flashiness index are computed. The results from the present study show that the streamflow is more sensitive to the precipitation than the temperature. With the same spatial pattern as observed the magnitude of the rainfall, evapotranspiration and runoff has increased over the basin. An increasing trend in the non-monsoon season is observed for the rainfall and runoff than the monsoon period. The water availability has increased in the range between 20%-90% probability of exceedance. The projected areal index of the drought condition is going to be decreased under both the future scenarios.

**CIVIL ENGINEERING**

Author : **K PRAVEEN**

Title of the thesis : **STUDIES ON SHEAR BEHAVIOUR OF RECYCLED**

**AGGREGATE BASED STEEL FIBER REINFORCED SELF**

**COMPACTING CONCRETE**

Guide : **Dr. S. VENKATESWARA RAO**

Degree : **Ph. D.**

Student ID No. : **701404**

ABSTRACT

Of all the different kinds of failures in concrete, shear failure is a sudden and brittle and occurs abruptly without any prior warning. To avoid these types of failures in concrete beams are traditionally reinforced with stirrups at closer spacing based on design. Congested arrangements of rebars and stirrups in Reinforced Concrete (RC) members such as, columns, beams and slabs makes it difficult to compact concrete into every corner of form work by means of any mechanical vibrators. Unoccupied voids and macro-pores inside concrete arise from inappropriate vibration and compaction might affect the mechanical strength and durability of the concrete and possible reasons of deterioration in concrete. Self-Compacting Concrete (SCC), originally established by Okamura in 1986 is a well thought-out solution to solve the above stated problems. Self-Compacting Concrete (SCC) as the name itself indicates, no external effort in compacting the concrete, it compacts itself under its own weight.

Shear failure of conventional reinforced concrete beams usually occurs by tensile failure of concrete in the shear span. For this reason, shear failure in general is sudden and brittle, and in practice shear reinforcement in the form of stirrups are incorporated to prevent this type of failure, and to increase the shear strength of the beams. Addition of steel fibers in concrete improves the post cracking behaviour and enhances the flexural-tensile strength. In recent years, application of use of short steel fibers in concrete increased tremendously. Steel Fiber Reinforced Concrete (SFRC) is a composite material that is characterized by enhanced post-cracking behavior due to the capacity of fibers to bridge the crack faces if they are present in sufficient amount.

The nature of the construction industry is not environmentally friendly and the need for sustainable methods in construction is very crucial to ensure that natural materials are not depleted for future. The usage of cement and natural aggregate has increased drastically over the past few years in the construction industry. Due to depletion of natural resource such as lime stone and natural aggregates, there is an urgent requirement of replacing the main ingredients in concrete like cement and natural aggregates with locally available waste byproducts like mineral admixtures (flyash, GGBS, silica fume) as substitute to cement and recycled concrete aggregates to natural coarse and fine aggregates. The use of mineral admixtures as partial replacement to cement is a well-established fact that it helps in improving the strength and durability performance of concrete and it is used by many researchers and by construction organizations. Although, the use of recycled concrete aggregate is well recognized as a sustainable material that can replace the natural coarse aggregates and offers solutions to this problem, but it is still considered as inferior to natural aggregate in terms of its structural properties.

There are various softwares available to perform nonlinear analysis on reinforced concrete and to study the behaviour of fiber reinforced concrete (FRC) in flexure and shear. ATENA Gid is one such software developed exclusively to perform non-linear analysis on reinforced concrete. ATENA is a finite element based software used for nonlinear analysis of reinforced concrete structures. By using Atena software, the actual behaviour of reinforced concrete structures, such as concrete crushing, cracking and yielding of reinforcing can be analyzed.

Combining the above and from a detailed literature review, the following points were observed.

* Use of steel fibers in self-compacting concrete not only improves the load carrying capacity but also changes the failure pattern from a brittle behaviour to ductile mode.
* Effect of steel fibers on shear behaviour of Self compacting concrete needs to be established.
* Recycled aggregates can be used as replacement for natural aggregates and can be used in self-compacting concrete. The shear behaviour of recycled aggregate based SCC is to be investigated.
* Effect of stirrup diameter and spacing of stirrups on shear behaviour of SFRSCC needs to be investigated.
* Analytical modelling using a Finite element based software can be used in studying the shear behaviour of SFRSCC beams for both natural and recycled aggregates.
* The scope of the present investigation includes:
* Evaluation of strength properties of steel fiber reinforced self-compacting concrete for various dosages of steel fibers (0%, 0.25%, 0.5%, 0.75% and 1% by volume of concrete) for three grades of SCC i.e. M30, M50 and M70 and maximize the dosage of steel fibers.
* To study the shear behaviour of NASCC and RASCC beams for three span to depth ratios (a/d =2, 2.5 and 3) for both without and with steel fibers and compare the experimental results with various models available in the literature for vibrated concrete for 30 MPa and 70MPa strengths.
* To study the effect of stirrup diameter (6mm and 8mm Ø) and spacing of stirrups on shear behaviour of NASFRSCC and RASFRSCC beams of strength 30 MPa and 70MPa .
* Analytical modelling of steel fiber reinforced self-compacting concrete using a finite element software ATENA for both NASCC and RASCC for 30 MPa and 70 MPa concrete strength.
* To validate the experimental results with results obtained through analytical modelling using finite element software ATENA.

The following broad objectives have been formulated to study and validate the use of steel fibers in self-compacting concrete to evaluate the shear behaviour.

1. Evaluate the Fresh and hardened properties of steel fiber reinforced self-compacting concrete for various dosages of steel fibers (0%, 0.25%, 0.5%, 0.75 % and 1% by volume of concrete) for three grades i.e. M30, M50 and M70 and determine the optimal dosage of steel fibers based on fresh and hardened properties.
2. To investigate the shear behaviour of steel fiber reinforced self-compacting concrete for three shear span to depth ratios (a/d= 2, 2.5 and 3) for 30 MPa and 70 MPa strength concrete for both NASCC and RASCC.
3. To study the effect of stirrup diameter (6mm and 8mm ) and spacing of stirrups on shear behaviour of NASFRSCC and RASFRSCC beams of strengths 30 MPa and 70 MPa.
4. To correlate the experimental results with various models available in literature on vibrated concrete for both without and with steel fibers.
5. To validate the experimental results with results obtained through software ATENA for both NASFRSCC and RASFRSCC.

To achieve the above objectives and keeping in view the scope of the research work, a detailed experimental program was planned and the work was divided into four phases.

**Phase - I:**

Studies on fresh and hardened properties of steel fiber reinforced self-compacting concrete for various dosages of steel fibers (0%, 0.25%, 0.5%, 0.75 % and 1% by volume of concrete) for three grades i.e. M30, M50 and M70 and determine the optimal dosage of steel fibers based on fresh and hardened properties. The fresh properties include Slump flow test, V-funnel test, V-funnel at T5 minutes and J-ring test .The mechanical properties include compressive strength, split tensile strength and flexural strength. Also a preliminary study was carried out to know the difference on shear behaviour of SCC and NC.

**Phase - II:**

Studies on shear behaviour of natural aggregate based self-compacting concrete for three shear span depth ratios (a/d= 2, 2.5 and 3) and also to evaluate the effect of stirrup diameter (6mm and 8mm ) and spacing of stirrups for 30 MPa and 70 MPa strengths for both without and with steel fibers. To correlate the experimental results with various models available in literature for vibrated concrete.

**Phase - III:**

Studies on shear behaviour of recycled aggregate based self-compacting concrete for three shear span depth ratios (a/d= 2, 2.5 and 3) and also to evaluate the effect of stirrup diameter (6mm and 8mm ) and spacing of stirrups for 30 MPa and 70 MPa strengths for both without and with steel fibers. Correlate the experimental results with various model available in literature for vibrated concrete.

**Phase - IV:**

Analytical modeling of steel fiber reinforced self-competing concrete using both natural and recycled aggregates and to evaluate the effect of stirrup diameter (6mm and 8mm) and spacing of stirrups using a finite element software ATENA. Compare the experimental results with results obtained through analytical modelling for 30 MPa and 70 MPa strength SCC.

The parameters of investigation include

* Grade of concrete - SCC of grade M30, M50 and M70 for (preliminary study to determine the optimal dosage of steel fibers.)
* Dosage of steel fibers - 0%, 0.25%,0.5%,0.75% and 1 % by volume of concrete
* Strength of concrete - 30 MPa and 70 MPa ( adopted for casting of beams)
* Type of aggregate - Natural aggregate and Recycled concrete aggregate
* Shear Span to depth ratio (a/d) - 2, 2.5 and 3
* Diameter of Stirrup (Ø) - 6mm and 8 mm
* Spacing of stirrups (sv) - 𝐚 , 𝐚𝟐 ( where a is shear span)
* Dosage of steel fiber - 0% and optimal dosage of fiber ( adopted for casting of beams)

From a detailed experimental study on Shear behaviour of Steel Fiber Reinforced Recycled Aggregate based Self-Compacting Concrete, the following conclusions have been drawn.

1. Based on Fresh and hardened properties it can be confirmed that 0.5 % dosage of steel fibers by volume of concrete is maximum for self-compacting concrete in all the three grades (30MPa, 50MPa and 70 MPa). There is a good increase in the split and flexural strengths due to the fibres bridging the crack propagation resulting in increased ultimate load carrying capacity of the specimens.
2. The compressive strength increased by 4.9% whereas, split tensile by 15.44% and flexural strength by 22.3% for normal strength concrete (30 MPa) with the use of maximum dosage of steel fibers (i.e. 0.5% by volume of concrete).
3. In case of standard grade SCC (50 MPa) due to addition of maximum dosage of steel fibers(0.5% volume of concrete), the compressive strength increased by 2.63%, split tensile strength by 20.8% and flexural strength by 14.5%.
4. Similarly, in case of high strength SCC (70 MPa) due to addition of steel fibers, the compressive strength increased by 6.51%,split tensile strength increased by 12% and flexural strength by 21.67% with 0.5% dosage of steel fibers.
5. Due to addition of steel fibers, the ultimate shear strength increased by 36.8% and 15% in SCC30 and SCC70 respectively compared to plain beams. The failure mode changed from a sudden brittle failure to a ductile flexural type failure. This is true for both the stirrup diameters (6mm and 8mm).
6. Due to the combined effect of stirrups and steel fibers, the ultimate shear strength increased by 89.34% and 80.65% in SCC30 and SCC70 respectively compared to plain beams for beam with a/d=2 at 180 mm spacing.
7. With increase in the shear span to depth (a/d) ratio, the ultimate shear strength reduced by 5.2% and 22.54% for SCC30 for a/d =2.5 and 3 when compared with a/d=2. Similarly, in case of SCC70, it is reduced by 19.59% and 22.44% respectively. This behaviour was true in case of both fibrous and non-fibrous concrete beams with 8mm stirrup.
8. With increase in the area of shear reinforcement, the ultimate shear strength increased by 18.7% and 51.09% for SCC30-180 and SCC70-180. Similarly, the shear strength decreased with increase in the spacing of stirrups. It was also noticed that with the use of steel fiber reduction in area of stirrup was possible. Similar behaviour was observed in case of beams tested for shear span to depth ratio 2.5 and 3 also.

9. As the shear span to depth (a/d) ratio increased, crack angle (θ) has reduced and this is true for both grades SCC30 and SCC70. The Theoretical Shear Strength for NASCC is given by:

 𝐕𝐮= 𝐕𝐮𝐜+𝐕𝐮𝐬

 𝐕𝐮={𝐝𝐒𝐢𝐧𝛉∗𝐛∗𝐅𝐭 ∗𝐂𝐨𝐬𝛉}+{𝟎.𝟖𝟕∗𝐟𝐲∗𝐀𝐬𝐯𝐂𝐨𝐬𝛉 }∗𝐤𝟏 ; Where Ft = Split tensile strength of NASCC or NASFRSCC and θ = 50.459 - 3.2802(a/d).

k1=0, when crack does not cross the stirrup and k1=1 , when crack crosses the stirrup

10. The Analytical shear strength predicted based on Non-linear Regression analysis for NASCC is given by:

 Vu = (0.3\*fck)+(0.016\*Asv)-(0.001\*Sv)-(0.038\*Ast)-(0.712\*a/d) + (0.8\*Vf)

Where, fck = Compressive strength of concrete; Asv= Area of shear reinforcement, Sv = Spacing of stirrups, Ast = area of longitudinal reinforcement; a/d= shear span to depth ratio and Vf = Percentage of fiber (0.5)

11. With the use of recycled aggregates, the compressive strength decreased by 7.8% and 8% respectively for 30MPa and 70 MPa concrete.

1. The ultimate shear strength decreased by 12% and 10.2% in case of plain SCC beams with use of recycled aggregates. Similarly, in case of fibrous SCC beams the ultimate shear strength reduced by 2.36% and 6.98% respectively for standard (30 MPa) and high strength (70 MPa) SCC with respect to plain NA beams.
2. Due to addition of steel fibers in RASCC beams, the shear strength increased by 2.3% for 30 MPa and 1.2% for 70 MPa concrete, compared to plain NASCC beams.
3. The predicted theoretical shear strength for RASCC is given by:

 𝐕𝐮= 𝐕𝐮𝐜+𝐕𝐮𝐬 ;

 𝐕𝐮={𝐝𝐒𝐢𝐧𝛉∗𝐛∗𝐅𝐭 ∗𝐂𝐨𝐬𝛉}+{𝟎.𝟖𝟕∗𝐟𝐲∗𝐀𝐬𝐯𝐂𝐨𝐬𝛉 }∗𝐤𝟐 ; Where Ft = Split tensile strength of RASCC or RASFRSCC and θ = 50.459 - 3.2838(a/d).

k2=0, when crack does not cross the stirrup and k2=1 , when crack crosses the stirrup

1. The analytical shear strength predicted based on Non-linear Regression analysis for RASCC is given by

 Vu = (0.35\*fck) + (0.014\*Asv)-(0.001\*Sv)-(0.04\*Ast)-(0.73\*a/d) + (0.24\*Vf)

Where, fck = Compressive strength of concrete; Asv= Area of Shear reinforcement, Ast = area of longitudinal reinforcement; a/d= shear span to depth ratio and Vf = Percentage of fiber (0.5).

1. The Numerical results obtained compared well with those of the experimental results and the values are within 85-90% limits.
2. A correlation among experimental deflections and the deflections obtained though ATENA modelling are close to each other, with a percentage variation less than 15%.
3. A comparison of Numerical shear strength obtained based on ATENA modelling with the predicted theoretical shear strength was found to be satisfactory.

**CIVIL ENGINEERING**

Author : **M VENU**

Title of the thesis : **STUDIES ON BEHAVIOR OF TIE-CONFINED FLY ASH**

**AND GGBS BASED GEOPOLYMER CONCRETE UNDER**

**AXIAL COMPRESSION**

Guide : **Dr. T.D. GUNNESWARA RAO**

Degree : **Ph. D.**

Student ID No. : **714112**

ABSTRACT

Production of Ordinary Portland Cement (OPC) leads to huge emission of carbon dioxide into atmosphere contributing to greenhouse effect. To reduce the negative impacts on atmosphere, sustainable construction materials are being developed to over use of virgin materials used to produce concrete. In such context, the geological origin materials or industrial by-product materials rich in silica and alumina can be used in producing concrete. Many efforts are being conducted to reuse waste industrial processes (such as fly ash, blast furnace slags, etc.) in the manufacture of concrete.

In this study fly ash and GGBS are used as binders instead of ordinary Portland cement in the preparation of Geopolymer concrete. A suitable combination of fly ash and GGBS as binders in geopolymer concrete (GPC) results in high compressive strength even under ambient curing conditions. Many researchers reported the mechanical and durability aspects of GPC, but very few research works are focused on confinement effect of GPC. Though several investigators have proposed mix design for fly ash and GGBS based GPC but there is a less research work reporting the stress-strain behaviour of plain and tie-confined Geopolymer concrete. The confinement of GPC is very essential parameter as it improves the flexural strength, toughness and ductility as well as change the failure mode of concrete under flexural loading. The techniques of reinforcing and/or pre-stressing of concrete take care of its tensile capacity. However, these techniques improve the ductility of concrete. Thus, the present study is aimed to investigate the confinement effect of GPC by considering the parameters viz. tie reinforcement, alkaline/binder ratio, compressive strength of concrete. An experimental program was carried out to evaluate the confinement effect of geopolymer concrete prisms (200 mm \* 100 mm \* 100 mm) by varying the parameters like confinement index, compressive strength of GPC (20 MPa, 40 MPa, 60 MPa) and tie-configuration (6 mm, 8 mm).

The obtained results conclude that the modulus of elasticity increases with an increase in the compressive strength of concrete, and an equation is proposed for calculating the modulus of elasticity based on the compressive strength of the GPC. It is also found that the modulus of elasticity of fly ash and GGBS based geopolymer concrete is lower that of conventional concrete obtained based on the formula given in IS456-2006 (5000√fck). Equations are proposed to determine the ultimate strength and strain at ultimate stress of Geopolymer concrete in terms of confinement index. A non-dimensionalised stress-strain equation was developed adopting Sargin’s model to predict stress-strain behaviour of tie-confined geopolymer concrete under axial compression.

To validate the proposed semi-empirical equation and also to predict the momentcurvature (M-Ø) relationship, under and over reinforced beams (1800 mm \* 200 mm \* 120 mm) were cast by varying compressive strength of geopolymer concrete (20 MPa, 40 MPa, 60 MPa). The experimental M-Ø results were compared with analytical M-Ø relation developed using MATLAB programming. The results indicated an error less than 15% by comparing experimental and predicted moments and its corresponding curvatures. Increase in strength of concrete increases the ultimate moment carrying capacity but decreases the curvature marginally. However, the predicted analytical value is only slightly lower than that of the experimental values. Hence the M-Ø relationship of the geopolymer concrete beam at ambient temperature is found to be satisfactory and it could be predicted well by adopting strain compatibility criteria.

**CIVIL ENGINEERING**

Author : **NOOLU VENKATESH**

Title of the thesis : **STUDIES ON RESILIENT AND PERMANENT**

**DEFORMATION CHARACTERISTICS OF GRANULAR**

**PAVEMENT LAYERS**

Guide : **Dr. M. HEERALAL**

Degree : **Ph. D.**

Student ID No. : **714108**

ABSTRACT

Civil engineering practice has gone a long way from using California bearing ratio (CBR) value alone for designing of flexible pavements. Empirical methods of design have given way to limiting shear failure methods, limiting deflection methods, regression method based on pavement performance or road test and finally landing up on Mechanistic Empirical Pavement Design methods. Mechanistic-empirical design practice for flexible pavement as suggested by AASHTO relies mainly on the resilient modulus of the granular materials. Though the resilient modulus is assumed to account for plastic strain accumulation, some subgrade soils with more fine content undergo excessive plastic deformation under repeated loads even though they have remarkable resilient properties. Hence, permanent deformation is also an important parameter, which should be considered in the design process. In the presentthesis investigations are carried out to study the resilient and permanent deformation characteristics of granular materials. Two clayey soils, with intermediate plasticity and high plasticity are selected for the experimental work. Stabilization of clayey subgrade will be essential for better long term performance of the flexible pavement. Studies regarding the resilient and permanent deformation characteristics of chemically stabilized subgrade materials are also very less reported in the literature. Calcium carbide residue(CCR) is a by-product from acetylene factories is used to improve subgrade soils in the present work. Utilization of recycled aggregates as a subbase material is also considered in the present study. The resilient and permanent deformation behaviour of both natural and recycled aggregates are compared.

As the first research objective, an attempt has been made to evaluate the potential of calcium carbide residue as an admixture to improve the engineering behaviour of the two clayey soils (both CH and CI). The role of different percentages of these binder contents in altering the atterberg limits, compaction characteristics, strength, mineralogical and morphological behaviour has been examined. The plasticity properties and compaction characteristics of both clayey soils have improved considerably with the addition of calcium carbide residue. Significant improvement in the strength properties such as unconfined compressive strength and California bearing ratio has been observed with the addition of calcium carbide residue up to 8% for the black cotton soil, whereas for red soil the maximum strength was observed at 4% binder content. The increase in strength can be attributed to the formation of calcium-based minerals formed as a result of pozzolanic reactions in the soil-binder mixture which is confirmed from mineralogical and morphological studies. Second objective of the present study is to evaluate the influence of calcium carbide residue in resilient modulus of clayey subgrade soils. The improvement in resilient modulus of two clayey soils (with low plasticity and high plasticity) with the addition of calcium carbide residue is investigated by carrying out repeated load triaxial (RLT) tests. The influence of variation in moisture content, deviatoric stress and confining pressure on the repeated loading behaviour of virgin soils and CCR stabilized soils is examined. Two regression models (Universal and NCHRP model) reported in literature are found to exhibit very good fit with the experimental data. Third objective is to examine the permanent deformation behaviour of clayey subgrade soils by subjecting the samples to large number of loading cycles in cyclic triaxial apparatus. The influence of confining pressure, moisture content and deviator stress levels on the permanent deformation behaviour is examined. Effect of calcium carbide residue on permanent deformation behaviour of both the clays is analysed. The transition of the soil sample from stable to unstable state can be observed and critical stress levels established with the help of shake down theory. Based on the experimental investigations it is observed that in the case of black cotton soil specimens prepared at OMC, the elastic shakedown limit is at 50% stress level, whereas plastic creep stage is observed at 60% stress level. For a higher water content OMC+2% and OMC+4%, the elastic shake down range is found to be in between 40% and 50% stress levels and the plastic creep stage commenced at 40% stress level. For Red soil, the elastic shakedown limit for samples prepared at OMC is found to be at the 30% stress level, whereas plastic creep stage is observed at 40% stress level. For a higher moulding water contents of OMC+2% and OMC+4%, the elastic shake down range is observed below 20% stress level and the plastic creep stage commenced at 30% stress level itself. Therefore, it can be inferred that with increase in the sub-grade water content, the stress level corresponding to shakedown decreases, leading to rutting under repeated load. The stabilization with calcium carbide residue is found to be more effective in worst case scenario with higher water content and cyclic stress levels. Two regression models reported in the literature, Power law model and VTT model, are used to predict the plastic strains with a number of load cycles and stress levels as the variables. Fourth objective is divided into two phases. The first phase deals with the comparison of resilient and permanent deformation behaviour of natural and recycled aggregates. Effect of confining pressure and deviatoric stress levels on resilient and permanent deformation of natural and recycled aggregates were investigated. The permanent deformation behaviour is quantified using the critical cyclic stress levels based on the shake down theory. The experimental data for the permanent deformation of the aggregates is also found to fit well with VTT model and power law model. The second phase deals with pavement model tests carried out on test tank with untreated and treated clayey soil as subgrade material and the natural aggregate as the base material.

**CIVIL ENGINEERING**

Author : **P NAGA SOWJANYA**

Title of the thesis : **CLIMATE CHANGE IMPACT STUDIES FOR WATER**

**RESOURCES OF WARDHA AND KRISHNA RIVER**

**BASINS**

Guide : **Dr. K. VENKATA REDDY**

Degree : **Ph. D.**

Student ID No. : **701338**

ABSTRACT

Climate change is a global phenomenon having varying degrees of regional impacts. Management of river water is an important aspect for governing the political and economic affairs of any country. With the increasing pace of climate change, it has become indispensable to evaluate the impact of climate change over a river basin for efficient management of water resources. To assess the climate change induced impact at basin level, Regional Climate Models (RCMs) database is the most credible source. The RCM database contains the dynamically downscaled products of the coarser resolution Global Climate Model (GCM) outputs to a finer resolution by incorporating the physical laws, boundary conditions and atmospheric processes. Future projections of important meteorological variables of Representative Concentration Pathways (RCP) 4.5, 8.5 climate change scenarios are available for 5 different high-resolution GCM outputs under COordinated Regional Downscaling Experiment (CORDEX). Moreover, encompassing the uncertainty analysis with the future projection will improve the predictability and robustness of real time prediction.

In this research work, RCM database has been used to assess the climate change impact on water resource of river basin, Uncertainty analysis associated with multi model RCMs, meteorological and streamflow drought indices and trend analysis of streamflow for future projections. Spatio-temporal variations of water balance components have been studied with induced climate and Land Use Land Cover (LULC) changes and rule curves are developed for reservoir operating system based on the impact analysis using Stochastic Dynamic Programming (SDP).

Initial part of the research is devoted to investigate the variations in stream flow of Wardha watershed, India under changing climatic conditions. Regional Climate Models (RCMs) data with Representative Concentration Pathway (RCP) of 4.5 and 8.5 scenarios were used to simulate the streamflow for the Historic and Future periods using Soil and Water Assessment Tool (SWAT) model. Sequential Uncertainty FItting (SUFI-2) algorithm of SWAT calibration and uncertainty program (SWAT-CUP) was used for sensitivity analysis, calibration and validation of the SWAT model. SWAT simulated streamflow for the future period has been analysed by dividing the total period into four twenty years spans as 2020-2039, 2040-2059, 2060-2079 and 2080-2099. The results indicate a decrease in future streamflow compared to earlier periods. Intra and Inter annual variability of stream flows for the future periods is less as compared to historic period.

Krishna river basin, which is over utilized and highly sensitive to climate change was investigated to evaluate the future projections of monthly streamflow under different climate forcings. The uncertainty associated with the multiple RCMs is analysed using Reliability Ensemble Averaging (REA) method. SWAT hydrological model is used to simulate the future projection of streamflow over the basin and model parameters are optimized using SWAT-CUP at multiple gauging stations. The analysis was carried out for four 25-year time slices as Historic (1980-2004), Future1 (2020-2044), Future 2 (2045-2069) and Future 3 (2070-2094). The results indicate that REA data projects reasonably close values when compared to observed values in the middle and lower parts of the Krishna basin. Spatial and temporal variations of ensemble climate variables on annual, seasonal and monthly bases are prepared. Future projections of the precipitation show a decrease of about 20% in the Future period I. Absolute and relative changes in future streamflow compared to historic streamflow projects lower values in monsoon period and higher values in other periods at Huvinhedgi, Mantralayam and Pondhugala gauge stations. Trends in the streamflow throughout the basin show a decrease in the first future period when compared to the other two future periods. The recommendations made from this research work can be used as preliminary measures for formulating water management and adaptation practices for Krishna River basin.

Meteorological and streamflow drought indices are quantified for the future projections (2020 to 2099) using Standardized Precipitation Index (SPI) and Streamflow Drought Index (SDI) for the Krishna river basin. The results show that drought events will be more severe in Tungabhadra and lower Krishna regions during future 1 period and more frequent drought conditions in Bhima, Upper and Middle Krishna regions in future 3 period. Similarly, SDI for the sub basins shows that Tungabhadra basin is less effected by drought whereas Bhima, Middle and Lower Krishna regions will face more drought conditions in the future periods.

The spatiotemporal change of the LULC plays a major role in estimating the reliable predictions in hydrology. In the present research work, combined impact of climate and LULC change on water balance components of Munneru, a sub basin of Krishna river has been carried out using Soil and Water Assessment Tool (SWAT). The decadal LULC change over time is detected for the years of 1985, 1995 and 2005. The dominant land use in the study area is Cropland/Irrigated land and major changes of land use identified are increase of urban area from 42.85km2 to 93km2 and deciduous forest from 821.74km2 to 922.87km2 of the total area during the 20-year period. The climate model database obtained projects decrease in precipitation until 2040. Hence, simulations were carried out by adapting LULC change from 1985 to 2005 and climate model data up to 2040. The results project an increase in Evapotranspiration of about 10%, 1.7%, 3.84% in the 2020, 2030, 2040 decades respectively. Decrease in surface runoff of about 50% is predicted in the next three decades with the predicted zero-base flows in most of the sub basins by 2040.

In this research work, adaptive policies are formulated for a reservoir based on climate change impact on water resources for future periods. Nagarjuna sagar dam is a multipurpose reservoir serving flood control, irrigation and hydropower generation located in Middle Krishna basin, India. Hydrologic impacts on the reservoir operation are mitigated considering the performance criteria evaluated using r package known as ‘reservoir’ for the adaptation policies. It is observed that the reliability decreases with the increase in vulnerability as a result of climate change if the Standard Operating Policy (SOP) using the current rule curves is employed. Hence Stochastic Dynamic Programming (SDP) is employed to develop a suitable adaptation policy to mitigate the impact of climate change. Storage yield curves are developed for all future scenarios with varying reliabilities to minimize the storage volumes to adapt to the climate change for proper management of resources. The monthly rule curves developed indicate that reservoir-operating rules may have to be revised in basins where climate change projects an increasing probability of droughts.

The climate change impact results obtained in this study for Wardha, Krishna, Munneru rivers can be used for devising suitable adaptation plans for managing water resources in these basins. Adaptive policies proposed for Nagarjuna sagar reservoir are useful for effective sharing of water resources between different stakeholders under climate change conditions. The methodology proposed in this research work can be used for other river basins in India and across the world.

**Keywords:** Adaptive policy, Climate Change Impacts, Drought, LULC, RCM, Reservoir performance, River basin, Streamflow, Uncertainty.

**CIVIL ENGINEERING**

Author : **P SWAMY NAGA RATNA GIRI**

Title of the thesis : **CONSTITUTIVE BEHAVIOUR OF TIE CONFINED SELF**

**CURING SELF COMPACTING CONCRETE (TCSCSCC)**

Guide : **Dr. G RAJESH KUMAR**

Degree : **Ph. D.**

Student ID No. : **701334**

ABSTRACT

Strength and deformation are interrelated and needs to be considered simultaneously in the flexural design of RC beams. Evaluation of deformation is independent of some key parameters like concrete strength, steel yield strength and level of confinement. Out of these parameters, concrete strength is interlinked with many factors like mixing, placing and curing. While mixing and placing are taken care by adopting new methodologies in construction industry like Self Compacting Concrete (SCC), curing of concrete, is largely neglected and needs to be taken care using effective curing techniques. During hydration, there is a need to maintain higher relative humidity. The decrease in relative humidity will cause self desiccation or autogenous shrinkage at micro level. To prevent this problem, it is imperative that embedded water is made available for curing and this can be done by using self curing compounds and/or recycled aggregates which can act as internal curing agents.

SCC has excellent applicability in elements with congested reinforcement and complicated shapes and sizes. The compactness of SCC matrix, due to higher amount of fines and extra fine particles, improves properties in the Interfacial Transisition zone (ITZ). Curing, especially at early ages is very important as this is related to the early activity of C-S-H gel formation. The normal conventional curing methods may fail to meet the requirements of required hydration as evaporation of water cannot be avoided. Hence, use of internal curing techniques i.e. Light weight aggregates, super absorbent polymers and hydrophilic chemicals can be experimented as alternative curing techniques for improving the performance.

Depletion of natural sources and scarcity of material forced engineers to think in terms of sustainable development. During the last few decades, there has been enormous thrust on implementation of green technology. For maintaining harmony and protect the limited amount of natural sources available, reuse of construction demolished waste as aggregates in concrete is becoming inevitable. Use of recycled aggregate (RA) in concrete is a desirable alternate material for natural aggregate (NA) keeping in view of sustainability. The structural behaviour of this concrete is influenced by variation in type of processing, w/c ratio and replacement of RA in concrete. Recycled aggregates can also help in curing process, due to the presence of pores in the adhered mortar on the top surface of aggregates; the pre-soaked aggregates can act as water reservoirs similar to light weight aggregates and super absorbent polymers. Further, the use of self curing chemicals in recycled aggregate based concretes can benefit such concretes in terms of internal curing and internal sealing also.

Concrete is a versatile material, however, the major deficiency is the brittleness of concrete. This can be overcome by providing suitable confinement to concrete in the compression zone. A method of confining concrete in structural members is by providing spirals, ties, fibers, FRP’s, Ferrocement etc. Circular binding is more efficient than rectangular binding in confining the concrete, because, in the former case, the confinement effect is developed by hoop tension. Confinement produces a tri-axial state of stress, due to which, the strength and deformation increases, the later increases to a greater degree. As flexural members are usually rectangular in shape, a rectangular tie is preferred. When confined with such spirals/ties, the deformable capacity of the section is improved and hence, the moment-curvature characteristics of such a cross section tend to be similar to that of steel section. However, the level of confinement required for a particular type and grade of concrete need not be the same.Apart from compaction, curing is an important aspect which is largely neglected and compressive strength has a bearing on the curing of concrete. In this context, investigating the influence of self curing agents on the structural behaviour of SCC is important.

The following broad objectives have been formulated to study and validate the efficacy of the chosen self curing SCC and investigate the structural behaviour of such a material.

* + 1. To develop Self Curing SCC with natural aggregates and thus evolve the Stress-Strain behaviour and stress block parameters for Tie Confined Self Curing Self Compacting Concrete.
    2. To develop Self Curing SCC with recycled aggregates and evolve the Stress-Strain behaviour and stress block parameters for Tie Confined Self Curing Self Compacting Concrete.
    3. To develop analytical Moment-Curvature relationship for tie confined self curing self compacting concrete for both natural and recycled aggregates.
    4. To validate the proposed analytical Moment-Curvature with suitable experimentation based on flexural studies on simply supported RC SCC beams.

To achieve the above objectives and keeping in view the scope of the research work, a detailed experimental program was planned and the work is divided into four phases.

**Phase-I:**

Studies on Self Curing Self Compacting Concrete with natural aggregates and thus evolve the Stress-Strain behaviour and stress block parameters for Tie Confined Self Curing Self Compacting Concrete.

**Phase - II:**

Studies on Self Curing Self Compacting Concrete with recycled aggregates and thus evolve the Stress-Strain behaviour and stress block parameters for Tie Confined Self Curing Self Compacting Concrete.

**Phase - III:**

Developing the analytical Moment-Curvature relationship for tie confined self curing self compacting concrete (TCSCSCC) for both natural and recycled aggregates.

**Phase - IV:**

Validation of the proposed analytical Moment-Curvature with suitable experimentation, based on flexural studies on simply supported self curing self compacting RC beams.

With the use of hydrophilic (PEG 4000 & PEG 200) as self curing agents in SCC studies were undertaken on fresh and hardened properties of two grades of natural (NA) and recycled aggregate (RA) based SCC subjected to various curing conditions (Conventional curing, No curing and Self curing). The following are the broad conclusions drawn:

* Lower dosage of high molecular weight (0.1% of PEG 4000) hydrophilic chemical improved the water retention better in higher grade concretes (Mix A). While in case of Mix B i.e. lower grade concrete, higher dosages (1.0% of PEG 4000) was necessitated.
* In case of Mix A- NASCC specimens, there is a decrease in compressive strength by 22% for no cured specimens compared to conventional water cured specimens. With the use of optimum amount of PEG 4000 (0.1%), this loss was compensated by 20%.
* In case of Mix A and Mix B-RASCC specimens, the optimum dosage of self curing agent (PEG 200) is 0.1% with respect to water retention and compressive strength tests. Improved performance was observed in self cured RASCC specimens compared to no curing and the values were on par with wet cured RASCC specimens.
* The stress-strain relationship for Tie Confined Self Compacting Concrete (TCSCC) is developed for different curing conditions.
* A common non-dimensional characteristic equation is proposed for the stress strain curve of natural aggregate and recycled aggregate based Tie confined SCC under different curing conditions.
* An analytical moment–curvature relationship for self compacting concrete beams is proposed by considering the common stress-strain curve developed in line with the Saenz’s model for both conventional and self curing natural and recycled aggregates based TCSCC.
* Use of self curing agents in SCC improved the moment carrying capacity of the beams and was closer to water cured specimens. This is true for both NASCC and RASCC beams. However, the moment carrying capacity observed was high in natural aggregate based SCC beams compared to recycled aggregate based SCC beams.

It can in general be concluded that with optimum dosages of self curing chemicals in SCC the structural behaviour in terms of stress-strain and moment - curvature relationship was almost similar to water cured specimens.

**CIVIL ENGINEERING**

Author : **POOJARI YUGENDAR**

Title of the thesis : **MICRO AND MACROSCOPIC ANALYSIS OF CROWD**

**BEHAVIOR**

Guide : **Dr. K. V. R. RAVI SHANKAR**

Degree : **Ph. D.**

Student ID No. : **715002**

ABSTRACT

Development of cities across the globe is unstoppable and it‟s very difficult to carefully plan cities. In this situation, understanding pedestrian movements is very essential for design facilities with respect to safety, security, level of service and low cost. Religious occasions, congregations at carnivals, political rallies, and crowd at terminals are occasions pertaining to crowd congregations. These congregations act as serious intimidations for the crowd, because a large number of people moving in limited space results in crowd stampedes. Most of the crowd crushes occurr in developing countries during large congregations and more people die when compared with developed countries (Andrade et al. 2006). Prassana Kumar et al. (2015) stated that on an average more than 70 people per year lost their lives due to stampedes in India. Indian states of Maharashtra and Andhra Pradesh are in top the list of more than 300 deaths in the 15 years (2001-15). Hence, it is very important to study crowd behavior to increase public safety. Understanding crowd behavior and the tools required to forecast crowd behavior are necessary in planning and design facilities such as bus terminals, train platforms, etc.

Three locations were selected for the study: Location-1 is situated in Vijayawada, Andhra Pradesh, India, whereas Location-2 is situated in Medaram, Telangana, India and Location-3 is situated in NIT, Warangal, Telangana. Data was collected by placing digital camera on top of the building. The videos were taken from a high-raise point near the location to avoid occlusion problem during tracking. Camera stands were used to ensure the videos recorded were steady, without any disturbance that might affect the frames at various stages of analysis. Markings were made on the road sections. Distance measurements were made using a standard tape such that the speeds could be cross-checked while extracting data using software.

Various parameters extracted from the video include people count, density, speed of individual persons, and crowd flow. Number of persons in a frame was counted using background subtraction technique. Speed and tracking of each individual were extracted using TRACKER software. Pixel coordinates were converted to real coordinates using the method of Wolf and Dewitt (2000).

In microscopic analysis, parameters like age, gender, group size, child carrying, child holding, and people with and without luggage were considered. For statistical analysis, ANOVA and Pearson correlation tests were performed using SPSS. From these tests, it was concluded that, there was a significant effect of age, gender, density and luggage on the crowd walking speed. Gender has more significant effect on speed followed by luggage and age. MLR, ANN, ANFIS models were developed for the modelling of crowd speed using the above mentioned factors in the study. The developed model was validated using RMSE (Route Mean Square Error) and MAE (Mean Absolute Error) values. Based on RMSE and MAE values, ANFIS model was observed to be better-fitted model when compared to other models. Gender, density and luggage have a negative effect on speed of the crowd while age has a conflicting effect on speed of the crowd. The increase in number of female persons in the crowd leads to speed reduction. Generally, the speed of the female person is low compared to male. Density is found to have an adverse effect on speed, whereas, at low crowd density, the speed of the crowd was high due to fewer interactions between persons and more space for overtaking. The speed was observed to be low at high crowd density because of more interactions between persons and little space for overtaking. Further, it was observed that luggage has an adverse effect on crowd speed. The speed of people with luggage is low when compared to people without luggage. Children and the old people were negatively associated with crowd speed. Also, as the number of children and the old people increases, it was found that the speed of crowd decreased. Additionally, younger and elder persons were positively associated with crowd speed. As the number of younger and elder persons increased, the speed of the crowd was observed to be higher.

In macroscopic analysis, flow parameters such as free flow speed (Uf), optimum speed (Uo), jam density (Kj), optimum density (Ko) and maximum flow (Qm) were estimated from the fundamental relationships. Flow–density and speed–flow relationships were then calibrated from the speed–density relationship. To determine the crowd characteristics, two single-regime speed–density models were used Model I - Greenshield‟s (L) and Model II - Underwood (E). Model I gave the minimum MAPE and RMSE values, which implies that Model-I gives better prediction than Model II for crowd movement. In real conditions, it is not possible to model the entire traffic mass as a single regime due to the existence of both uncongested and congested flow. A multi-regime model concept is thus essential to represent different flow conditions. For two-regime model, the speed–density relationship is developed for two regimes by introducing a breakpoint to distinguish between two different regimes. This breakpoint is identified by K-means clustering analysis using SPSS software. The final selection of the breakpoints was determined using a visual approach. Four models i.e., Model I, II, III and IV representing L-L, L-E, E-L, and E-E were used to determine the crowd characteristics in two-regime model. The minimum MAPE and RMSE values of the crowd characteristics (speed, density and flow) were obtained using Model III (E-L). Three-regime models consider uncongested flow, transitional flow and congested flow regimes. In three-regime models, the speed–density relationship is developed for three regimes by introducing breakpoints to distinguish between three different regimes. Four models i.e., Model I, II, III and IV representing L-L-L, E-E-E, E-E-L, and E-L-E were used to determine the crowd characteristics in three-regime model. Model-II (E-E-E), with the lowest MAPE and RMSE values when compared to all the four models, provided the best predictions. MAPE and RMSE values of the best multi-regime models were less than that of the best single-regime model. Therefore, multi-regime models provide better predictions than single-regime model. Of the multi-regime models, MAPE and RMSE values of three-regime models were less when compared to two-regime model, which implies that the three-regime model gives better predictions than two-regime models.

In capacity analysis, buffer space is introduced in this study to study the influence of overtaking within the crowd while evacuation. Therefore, this study is divided into two cases: presence of buffer space and absence of buffer space. The height and length of the bottleneck are constant. Five varied widths of bottlenecks which consisted of 80, 100, 120, 140, and 160 centimeters repectively were chosen. In this experiment, 30 and 50 individuals were involved in two different compositions. The evacuees were divided into two groups and assigned different walking responsibilities for every test (move slowly, and move fast). The groups were diverse and comprised male and female. Since the entire group of 50 was of same age group, the group was divided so as to incorporate the effect of age variation within the group. One group of evacuees was designated by the colour of their caps (white). Whereas, persons without caps represent normally acting participants, while the persons with caps follow specific instructions.

The first step in density estimation was the conversion of video into frames, and the next step was to divide the entire area (50 m2) into equal number of grids having a grid size of 0.5 × 1 meter. Further, using the manual count method, the number of persons in each grid was noted, and finally, the average values of densities (people/area) for all frames in each grid were computed. The whole study area was divided into grids, in order to calculate the density in each grid because it was not uniform throughout the study area. This also gives us an idea of the path/ route of evacuation chosen by most individuals at the time of evacuation. In crowd analysis, another issue involves the tracking of people and finding the location of the same person in a series of images. For this a free open source software TRACKER was used, which tracks persons semi-automatically.

From the experimental study, total time, time gaps, flow, specific flow and densities were extracted. It was observed that the total time decreased as the bottleneck width increased, for both compositions in cases with and without buffer space. The buffer space effect in the reduction of total time was more in case of 50 persons, when compared to 30 persons. It was observed that flow increased as the width of the bottleneck increased, and this increase in flow is due to the formation of dynamic layer, as noted by some researchers in their studies. It was observed that, specific flow was decreasing as the width of the bottleneck increases and specific flows were more for without buffer space as compared to with buffer space. Trajectories were plotted in order to know the route choice of each individual throughout the evacuation period in the study area. It can be identified that lateral occupancy of persons is more in the case of without buffer space as compared to with buffer space, for both compositions (N = 30 & 50).

Arching phenomenon was observed at the entry of exits; this was apparent when a crowd with highly anticipated speed tries to pass through a door in limited amount of time because of which the exit gets congested, and the crowd becomes arc-shaped. It can be observed that densities were decreasing as the width of the bottleneck increased. Density value was observed to be higher for groups of fifty, when compared to groups of thirty people for the same width of bottleneck. High densities were observed near the bottleneck opening when the flow gushing in goes beyond the capacity of the bottleneck, leading to jamming at the bottleneck. It can be observed that, flow of crowd increases as the width of bottleneck increases and this increase is stepwise, and not linear. When the crowd enters the bottleneck, formation of lanes occurs inside the bottleneck as width increases due to zipper effect. For a width of 80 cm, formation of lanes is absent. As the width increases from 80 cm to 100 cm, two lanes were formed and these lanes were continued and laterally expanded up to a width of 140 cm. For a width of 160 cm, it can be clearly observed that three lanes were formed. It can also be observed that the distance between these lanes does not influence bottleneck width (B).

Five types of distributions (i.e., exponential, displaced exponential, Gamma, displaced Gamma and semi-random) were tested to cover the random, intermediate and composite headways. Five types of distributions mentioned above have been compared with the observed data and tested with goodness of fit (χ2 test). It was found that, among five types of distributions, semi-random distribution is observed to be the best fit for the observed data. The percentage of constrained headways (ϕ) observed in case of 50 persons was more than that of 30 persons. This implies that free flow decreases with increase in number of persons. In order to estimate the capacity of bottleneck, Buckley model is used. It can be observed that, capacity of bottleneck increases as the width of the bottleneck increases and this increase in capacity is because of the dynamic layer formations due to zipper effect. It can also be observed that, capacity of bottleneck with buffer space is more compared to capacity without buffer space. The obtained capacities were compared with capacities from different experimental studies done in relation to pedestrian flows at bottlenecks. For comparison, Kretz and Muller studies were considered because of their similarity with this study. Capacities obtained in this study were lower than that of capacities obtained from Kretz and Muller. The reason behind the reduction in capacities was Kretz and Muller didn't consider the formation of dynamic layers, hence the effective utilization of width concept was absent, resulting in larger capacities in their study.

Further, the same experimental study area and participants were used for the estimation of capacity of doors. Five varied widths of the doors consisting of 80, 100, 120, 140, and 160 centimeters were chosen for single doors and doors of 100 cm width selected for double doors. Parameters such as total time, time gaps, and densities were extracted and analyzed in terms of various relations such as time gap versus door width, total time versus door width, and flow versus door width. Crowd trajectories and density plots were drawn for different door widths. Capacities were estimated both for single and double doors and comparison of capacities for different door widths was performed. Average time gaps and total times were observed to decrease as the width of the door increased, for cases with and without buffer space. In case of single and double doors, the total time was more in case of 50 persons than for 30 persons. Observations from trajectories have revealed a phenomenon called arching. In case of double doors, it was observed that evacuees were choosing the congested door rather than an uncongested one due to herding behavior. Herding behavior occurred when people were not making individual decisions but behaving as a group. In the evacuation scenario, herding behavior means that, the evacuees choose the most congested exit rather than the uncongested exit. Evacuees think that the congested exit is the most popular choice.

**CIVIL ENGINEERING**

Author : **S SRIKANTH**

Title of the thesis : **TRAFFIC FLOW MODELING AND SIMULATION OF**

**TRAFFIC FLOW BEHAVIOR UNDER MIXED TRAFFIC**

**CONDITIONS ON MULTILANE HIGHWAYS**

Guide : **Dr. ARPAN MEHAR**

Degree : **Ph. D.**

Student ID No. : **714110**

ABSTRACT

The mixed traffic behavior on multilane highways remains scarcely explored. Most of the studies on multilane traffic flow pertain to homogeneous traffic scenarios. These studies have very limited applications to mixed traffic conditions due to their incapability in satisfactorily explaining the complexities of mixed traffic behaviour. Also, the available literature on mixed traffic mainly deals with the single and two-lane roads and there is no comprehensive study for understanding traffic flow behavior on multilane highways. IRC: 64-1990 also provides detailed guidelines for capacity of single-lane, intermediate lane and two lane rural roads; leaving multi-lane highways almost unattended. Due to lack of standard codes for multilane highways in India, it is difficult for traffic engineers, policymakers and planners to take accurate decisions with respect to planning, design, and operations of these highways. The present research work aims at investigating the mixed traffic flow behaviour on highways for varying conditions of traffic volume. To understand the traffic flow behavior on four-lane divided highways under mixed traffic conditions, the arrival patterns of vehicles, time headway characteristics, speed characteristics, lateral placement of vehicles and overtaking behavior were analyzed.

The aim of the present study is to develop more appropriate models for estimating the passenger car units of different vehicle types on multilane highways, considering the limitations of available methods. Present study describes a modified methodology for estimation of PCU value of subject vehicles that includes the time headway as influencing parameter. The approach used in the present study is inspired from the method of dynamic PCU estimation where a PCU is expressed as the ratio of speed ratio and area ratio of standard cars to the subject vehicle type. Unlike dynamic PCU method, this method includes time headway factor for PCU estimation. The method was found to be more realistic and logical as it provides relatively higher values of PCUs than those obtained from dynamic PCU method.

Multiple non-linear regression (MNLR) method is proposed for estimation of equivalency units for vehicle types by developing speed models based on multiple non-linear regression approaches. The equivalency units estimated by using models are found to be realistic and logical under heterogeneous traffic flow conditions. The PCU values estimated by the multiple non-linear regression method are compared with and found to be relatively higher values than the values obtained by the dynamic PCU method. The accuracy of the models is checked by comparing the observed values of speed with estimated speeds. The multiple non-linear regression approach is also used for estimating the equivalency units on six-lane divided highways.

The primary limitations of field data arises due to practical difficulties in conducting extensive field experiments under wide variations of traffic flow parameters, non-availability of required field conditions, difficulty in experimenting with individual components in isolation, etc. As a solution to these practical problems, computer simulation has been proved to be a powerful tool in replicating complex traffic systems which allows experimentation to the basic traffic flow system. For the simulation VISSIM microscopic simulation tool is used and data analysis is performed by considering individual parameters and performance measures like speed, volume and random seed number. Statistical tests have been performed to check the sensitivity of the different simulation parameters and calibration is done using trial and error method and optimization is performed using solver function. The maximum simulated flow rate was found with default values as 4599 veh/hr, and with calibrated values is 5147 veh/hr which is close to the target capacity 4958 veh/hr as obtained using field composition. Calibrated values of CC0 and CC1 and CC2 parameters are found as most optimised values to achieve target capacity. Finally, validation of calibrated parameter values was also performed on other section of a multilane highway which have shown satisfactory results.

Lane changing is a very complex maneuver which can be studied through microscopic and macroscopic measures. Calibrated VISSIM model was used for generating traffic flow data to obtain the essential parameters. Lane change behaviour is analysed with homogeneous vehicle type traffic on four-lane, six-lane and eight-lane divided highways sections through VISSIM simulation model. The study finds the number of lane changes depends on traffic volume as well as on number of lanes provided for a direction of travel. Lane change data was correlated with traffic volume and third degree polynomial trend was found to be fitted on each type of simulated highway sections. Maximum number of lane changes and lane change at capacity level of volume are also quantified on simulated sections of four-lane, six-lane and eight-lane divided highways. It is found that no more number of lane changes is observed in all simulated sections when traffic volume reaches to maximum capacity. The relationship between capacity per lane and number of lane changes is established which shows capacity decreases with addition of number of lanes.

Level of service concept is applied in the present study to estimate the passenger car unit (PCU) value of each vehicle type at different level of service and different percentage share. Calibrated VISSIM model was used to simulate traffic conditions for the development of PCU models. The PCU value of each vehicle type at different level of service and different percentage share was found for the development of the models. The accuracy of the models is checked by comparing the obtained PCU values with PCU values estimated by dynamic PCU method. PCUs of different vehicle types at six lane and eight lane divided highways are also estimated. The effect of number of lanes on PCUs was studied, and it was observed PCU of each vehicle type decreases with increase in the number of lanes and at a different level of service. Artifical neural networks (ANN) and Artificial neuro fuzzy interface system (ANFIS) models are also developed for estimating PCU values of subject vehicle types with respect to passenger cars. The PCU estimated from different approaches are compared statistically in order to justify the best approach with the same set of input variables.

**CIVIL ENGINEERING**

Author : **SHARAT CHANDRA PILLALAMARRI**

Title of the thesis : **DESIRABLE PUBLIC TRANSPORT SHARES FOR**

**INDIAN CITIES**

Guide : **Dr. C.S.R.K. PRASAD**

Degree : **Ph. D.**

Student ID No. : **701051**

ABSTRACT

The theme of this research is to develop a desirable public transport (PT) share model for Indian cities. If cities are “engines of growth”, then the PT system is the fuel through which these engines derive its energy, and therefore, the extent of the PT system is one of the factors that influence the urban development. It is the critical stakeholder in urban 3Es (Economy, Environment and Equality) dynamism. Good public transportation increases the economic growth of a city (Economy), reduce energy consumption, emissions level (Environment) and increase accessibility to all levels of income groups’ (Equality).

In the absence of an adequate and efficient PT, many private and para-transit modes have entered into the market to meet the travel demand. The decline in PT shares is a severe concern regarding health, urban environment and city’s sustainable mobility. Due to the absence of clear guidelines to implement the PT system and level of desirable PT share to be achieved, cities are inconveniently moving towards alternative transport system. Out of 468 Indian class- I cities, less than 20% of cities are having organised PT system. Cities with a population of over 1 lakh (0.1 million) shall target for a minimum 30% PT share (MoUD 1987). However, even after 30 years of such policy in existence, only limited cities have reached this minimum. The need of the hour is to introspect these policy recommendations, revise the benchmarks if needed, incorporating the characteristics of the city.

PT is a function of various urban factors. Statistical evidence reveals that PT shares are influenced by urban variables such as population, urban form, density, average trip length, vehicle ownership, per capita trip rate, fare, public transport network density, fleet size, etc.

The research methodology is outlined in four phases. Phase-I discusses the review of the preliminary literature and research objectives. In phase-II, a comprehensive literature review was conducted and compiled the inferences from all the relevant works and methodological approaches related to the research. The secondary data collection process, data analysis and models development have been discussed in phase-III. The desirable PT share model approach, model development, study conclusions and recommendations have been addressed in phase- IV.

36 Indian cities and 11 International cities (restricted to the Asian continent) are analysed as part of the study. The cities are shortlisted based on the availability of data and its uniformity across different cities. The research study is significantly developed from secondary data. The determinants are then filtered by discarding correlated variables. The relevant variables of the existing PT model have been substituted with desirable variables to develop the desirable PT modal share model.

The research analysis revealed that city average trip length and population density are essential factors in PT share. The developed desirable PT model will help to propose the sustainable PT shares for Indian cities and support in the formulation of city transport policies.

**Keywords:** public transport, modal share, sustainability, desirable, mobility, class-I cities.

**CIVIL ENGINEERING**

Author : **SIEMPU RAKESH**

Title of the thesis : **STUDIES ON THE BOND BEHAVIOUR OF RECYCLED**

**AGGREGATE BASED SELF COMPACTING CONCRETE**

Guide : **Dr. P. RATHISH KUMAR**

Degree : **Ph. D.**

Student ID No. : **701402**

ABSTRACT

One of the reasons for success of reinforced concrete as a two phase building material lies in the perfect transfer of forces from a material that is relatively strong in tension to a material that is strong in compression and vice versa. This transfer of force is a result of loading on the member and results in shear stress along the contact surface of reinforcement and concrete. Bond is classified as anchorage/development bond and flexural bond. Anchorage/development bond is the case of tension or compression whereas, flexural bond comes into picture, where, there is change of bending moment along the length of the bar. Bond in reinforced concrete is achieved through three mechanisms; firstly, chemical adhesion which is due to the C-S-H gel that is formed as a product of hydration of cement, secondly frictional resistance that is offered by the surface of reinforcing bars and grip exerted due to concrete shrinkage and thirdly, mechanical interlock because of the ribs that are provided on the surface of the bar (absent in case of plain bars) (ACI 408, 2003).

The factors that influence the bond performance are mainly divided into three categories namely: structural characteristics, bar properties and concrete properties. In the present investigation, three major factors that influence the bond behavior namely, compressive strength of concrete, diameter of bar and embedment length of bar are addressed.

In order to determine the bond strength of reinforcement embedded in concrete, four tests are in practice namely, pull-out, beam-end, beam anchorage and splice test (ACI 408, 2003). Pull-out test is performed for evaluating anchorage or development bond and beam tests for determining the flexural bond. Of all these tests, to determine the bond strength, pull out test is widely adopted because of its ease of fabrication of the test specimen and simplicity of test. In a pull-out test, the bar is subjected to tension whereas, the surrounding concrete will be in compression. This stress state matches with few cases in actual construction. However, in other three bond tests, the steel as well as concrete will be in tension. Hence, determining the development length solely using pull-out test is not recommended by ACI 408 (2003) and any other tests like beam-end, beam anchorage and splice tests are to be performed in addition to pullout test. In the present investigation both pull-out and beam tests are performed.

Sustainable construction is the order of the day which can be achieved in construction industry. The term sustainability according to Brundtland (1987) is defined as “The development meeting needs of the present without compromising the ability of future generations to meet their own needs”. Construction industry is one of the major industries contributing to the emission of CO2 to the atmosphere. Sustainability can be achieved through materials used for construction, concrete production process, improving concrete properties and innovations in construction techniques. Few works were reported on the bond in recycled aggregate concrete (Xiao and Falkner (2007), Butler et al (2011), Prince and Singh (2013), Kim and Yun (2013 and 2014) and Guerra et al (2014)). The results concluded that the use of recycled aggregates reduce the bond stress in concrete compared to that of natural aggregate based concrete. The reduction in bond stress in the studies revealed an increase with increase in the replacement of natural aggregates with recycled aggregates. The normalised bond stress was however high in case of recycled aggregate based concrete.

Self-Compacting Concrete (SCC) is a high performance concrete which possess the abilities of flowing and passing without segregation in congested reinforcement locations. SCC, because of its self compactability, ensures uniform compaction throughout the length of the member resulting in reduced top-bar effect which is usually more significant in case of vibrated concrete (Valcuende and Parra, 2009). Several works were reported on the bond performance of Self Compacting Concrete (SCC) with natural aggregates in comparison with Vibrated Concrete (VC) (Almeida Filho et al (2008), Foroughi-Asl et al (2008), Sfikas and Trezos (2013), Pop et al (2013) and Helincks et al (2013)). The major findings are that SCC performed better in terms of bond compared to VC. This improved performance is attributed to the fact that the increased binder content reduce the pores in concrete leading to enhanced microstructure. As the quality of concrete encapsulating the bar increase in case of SCC compared to VC, the load carrying capacity required in pulling out of bar increases in case of SCC specimens.

The evolution of software packages based on finite element techniques have overcome the difficulties of materials, time and space and reduced the laboratory facilities for experimentation. A well-defined software model can predict the results closer to experimental values. The results of various works reported earlier on the use of finite element based software for modelling the bond between steel and concrete were found to be in close comparison with experimental results (Amleh and Ghosh (2006), Shafaie, Hosseini and Marefat (2009), Cheung, Leung and Kabele (2010), Almeida Filho and El Debs (2013), Tavares, Barbosa and Lorrain (2014) and Guerra, Ceia, de Brito and Julio (2014)).

SAP 2000 (SAP v19, 2017), ABAQUS (ABAQUS/CAE, 2017), ANSYS (ANSYS v18.2, 2017) and ATENA (ATENA v5.4, 2017) are some of the software packages available to help understand the behaviour of concrete. ATENA is employed for modelling the bond behaviour of steel and concrete. ATENA was developed by Cervenka Consulting, Czech Republic (ATENA v5.4, 2017). ATENA is a user friendly finite element based software specially designed for non-linear analysis of concrete and fibre reinforced concrete. It simulates the real behaviour of concrete and reinforced concrete structures including cracking, crushing and reinforcement yielding. ATENA uses all the material properties based on cube strength using equations from the fib Model Code 2010 (2013).

From a detailed review of literature the following are the observations:

* + 1. Studies reported on the influence of various factors that affect the bond between steel and concrete focused on natural aggregate based vibrated concrete. Some works on the bond behaviour of natural aggregate based self compacting concrete were also reported.
    2. The use of recycled aggregates (both coarse and fine aggregates as 100% replacement) in concrete and their effect on the bond between steel and concrete was not investigated. This is a potential area of investigation. The bond behaviour of recycled aggregate based vibrated and self compacting concretes needs investigation.
    3. The models proposed by several researchers and standard codes of practice for predicting the bond stress is based on the work done on natural aggregate based vibrated concrete. There is a need to develop a model for recycled aggregate based vibrated and self compacting concretes.
    4. The work reported in the literature on the bond behaviour is mainly based on “pull-out” tests. There is a need to study the bond behaviour based on flexural bond tests for validation.
    5. The use of finite element based software for analysis of concrete problems is gaining attention due to numerous advantages. ATENA is one such finite element based software developed for non-linear analysis of reinforced concrete. This software can be used to analyse the bond behaviour in concrete also.

The scope of the present investigation includes the following:

* Developing analytical model for predicting the maximum bond stress in natural and recycled aggregate based vibrated concretes.
* Understand the bond behaviour of self compacting concrete with surrounding reinforcement with natural and recycled aggregates and develop an analytical model for predicting the same.
* Validation of the proposed analytical model based on pull-out test for predicting the bond stress by conducting flexural pull-out test.
* Numerical modelling of the pull-out behaviour of plain and ribbed bars using finite element based software ATENA.

Based on the conclusions from the literature review the following objectives are defined for the present investigation.

* + 1. To study the bond behaviour in Self Compacting Concrete (SCC) and compare with that of Vibrated Concrete (VC) and propose an analytical model to predict the bond stress.
    2. To evaluate the effect of Recycled Aggregates (RA) on the bond behaviour of vibrated and self compacting concretes and propose an analytical model to predict the maximum bond stress.
    3. To validate the proposed analytical model thorough flexural bond tests and determine the effect of cover to bar on the bond stress.
    4. To determine the effect of type of bar i.e plain and ribbed in VC and SCC by using numerical modelling through finite element software (ATENA).

To achieve the above formulated objectives, a detailed experimental program is designed and carried out in four phases.

**Phase – I**

Bond behaviour of Natural aggregate based Vibrated Concrete (NA-VC) and Natural Aggregate based Self Compacting Concrete (NA-SCC) was evaluated by conducting pull-out tests. Based on the experimental results obtained, an analytical model is proposed to predict the bond stress in concrete. The model is compared with the available models in the literature.

**Phase – II**

Bond behaviour of Recycled Aggregate based Vibrated Concrete (RA-VC) and Recycled Aggregate based Self Compacting Concrete (RA-SCC) was established. A comparison is made with the results of corresponding natural aggregate concrete specimens. An analytical model was proposed to predict the bond stress in concrete. A common model covering the natural and recycled aggregate is brought out.

**Phase – III**

Tests on NA-VC, NA-SCC, RA-VC and RA-SCC beam specimens were conducted and flexural bond stress was determined. The validation of the proposed analytical model based on the pull-out tests is done using the experimental flexural bond stress results. Also, the effect of variation in cover to the bar is studied.

**Phase – IV**

The bond behaviour of both plain and ribbed bars in NA-VC, NA-SCC, RA-VC and RASCC is studied using ATENA software. The results of the ribbed bar are compared with the experimental results of the pull-out test.

The present investigation is divided into four phases and the various factors that influence the bond behaviour in the investigation are listed below.

1. Type of concrete – Vibrated Concrete (VC) and Self Compacting Concrete (SCC).
2. Type of aggregate – Natural Aggregate (NA) and Recycled Aggregate (RA).
3. Grade of concrete – Mix-A, Mix-B and Mix-C.
4. Diameter of bar (D) – 10, 12 and 16 mm.
5. Embedment length of bar (L) – 2.5D, 5D and full depth of the specimen. (for pull-out test)
6. Cover to bar (C) – 16 and 40 mm. (for flexural bond test)
7. Type of bar – Plain (P) and Ribbed (R) bars (for numerical modelling).

Based on the experimental investigations carried out on bond behaviour of natural and recycled aggregate based vibrated and self compacting concrete by conducting pullout and flexural bond tests, the following conclusions are drawn:

1. Self Compacting Concrete (SCC) specimens exhibited higher bond stress than the corresponding Vibrated Concrete (VC) specimens. The average percentage increase in bond stress was marginal at 5.10, 2.93 and 1.55 in case of mixes A, B and C respectively.
2. With increase in the concrete strength, the bond stress increased. The average percentage increase in bond stress in case of NA-VC for mix-A to mix-B and mix-B to mix-C was 11.07 and 12.00 respectively. In case of NA-SCC, this average percentage increase was 8.79 and 10.50 respectively.
3. With increase in the embedment length from 2.5D to 5D, the average percentage decrease in bond stress was 27.70, 28.79 and 29.45 respectively with three bar diameters 10, 12 and 16 mm for NA-VC. In case of NA-SCC this percentage decrease was marginally lower at 27.21, 28.72 and 29.25 respectively.
4. The slip, defined as relative movement between steel and concrete was found to be high in case of NA-SCC compared to NA-VC. This can be attributed to better bond in SCC. With increase in concrete strength, bar diameter and embedment length, there is an increase in slip and this was true in both NA-VC and NA-SCC specimens.
5. NA-SCC specimens exhibited higher fracture energy than the corresponding NA-VC specimens and this increased with increase in slip. There is a good correlation between fracture energy and slip.
6. There is a general reduction in bond stress with the use of recycled aggregates in concrete. The average percentage decrease in bond stress was 7.81, 10.10 and 12.60 in case of mixes A, B and C of RA-VC. In RA-SCC, this percentage decrease was 7.44, 9.71 and 11.73 respectively.
7. The slip and fracture energy both reduced with the replacement of natural aggregates with recycled aggregates in both vibrated and self compacting concrete. This is true in all the mixes A, B and C.
8. A relationship was established between fracture energy and slip and it was noticed that there is an increase in fracture energy with slip. The relationship is having a correlation of about 85% in case of both VC and SCC specimens.
9. The flexural bond stress of self compacting concrete specimens is higher than the corresponding vibrated concrete specimens. The average percentage increase in flexural bond stress of NA-SCC compared to NA-VC for mixes A, B and C was 6.29, 4.09 and 1.92 respectively. This average percentage increase in RA-SCC was 6.34, 3.95 and 2.24.
10. The replacement of natural aggregates with recycled aggregates in concrete decreased the bond stress. The average percentage decrease in maximum flexural bond stress of RA-VC compared to NA-VC was 7.12, 9.76 and 12.60 in case of mix-A, mix-B and mix-C respectively. In case of RA-SCC this average percentage decrease was 7.09, 9.88 and 12.33.
11. The average maximum percentage variation between the bond stress from proposed model based on pull-out test and experimental flexural bond test values is within ±15% (11.09%, 12.36%, 13.28% and 12.64% in case of NA-VC, NA-SCC, RA-VC and RA-SCC respectively).
12. The results of the pull-out model obtained for ribbed bars from ATENA (ATENA v5.4, 2017) are compared with the results of pull-out experiments. An average percentage deviation of 11.08, 15.88 and 10.53 was observed in case of embedment length to bar diameter ratio (L/D) 2.5, 5 and 10 respectively for different concrete types (NA-VC, NA-SCC, RA-VC and RA-SCC).

**CIVIL ENGINEERING**

Author : **SRIKANTH KONIKI**

Title of the thesis : **STUDY ON INFLUENCE OF FIBER HYBRIDIZATION**

**ON STRENGTH AND CONSTITUTIVE STRESS-STRAIN**

**BEHAVIOUR OF CONCRETE**

Guide : **Dr. D. RAVI PRASAD**

Degree : **Ph. D.**

Student ID No. : **714106**

ABSTRACT

Concrete is a widely used construction material all over the world. Since the problems associated with concrete such as low tensile strength and low ductility is limiting the usage in all practical applications. Short randomly discrete fibers used in concrete to control cracking in fresh and harden state of the concrete. But the improvement in mechanical properties with the addition of fiber is limited in extent as the fracture in concrete is gradual and multi scale process. This necessitates the addition of two or more different kind of fibers to improve the wide range of concrete properties such as shrinkage resistant, tensile strength and toughness.

This research was under taken with an objective to evaluate the mechanical properties and constitutive stress-strain behaviour of hybrid fiber reinforced concrete. Effect of fiber hybridization on different grades of concrete i.e., 30 MPa (low strength), 50 MPa (medium strength) and 70 MPa (high strength) concretes was studied. Fibers used in the present investigation were hooked end steel, polyester and polypropylene. Entire experimental programme was carried out in four different phases.

First stage of the investigation is carried out on mechanical properties and constitutive stress-strain behaviour mono-FRC. Compressive strength, direct tensile strength, flexural strength of mono-FRC are determined. The stress-strain behaviour of mono-FRC under uni-axial compression and tension are also assessed. Fiber dosages of polyester and polypropylene are varied from 0.0, 0.05, 0.1, 0.15 and 0.2% and the fiber dosage of steel fiber is varied from 0.0, 0.5, 0.75, 1 and 1.25%. From the results it is observed that there is no significant improvement in compressive strength with the addition of fibers, but tensile strength and flexure strength of the concrete increased with the addition of fibers. It is also noticed that concrete containing non-metallic fibers dose not significantly enhanced the both pre-peak and post-peak behavior of concrete under uni-axial stresses, whereas addition of steel fibers enhanced the post-peak toughness but the tensile strength of the concrete is not significantly improved. Results obtained from the phase I gave an idea about mono-fiber behaviour in concrete and paved the way for developing the HFRC in the further investigation.

The second phase of the investigation is carried out to develop and study the mechanical properties of non-metallic HFRC. The non-metallic HFRC aims to counteract the plastic shrinkage cracks forming at early stages of concrete and also to bridge the micro-cracks forming at low-stress levels of harden concrete. Even though Young’s modulus of both polyester and polypropylene fibers are nearer, due to the variation in tensile strength and aspect ratios of the fibers, the tensile strength of the concrete improved without compromising the plastic shrinkage cracks. Three types of hybrid combinations are considered i.e. PP 25% + PO 75%, PP 50% + PO 50% and PP 75% + PO25% at a total fiber volume fractions of 0.1, 0.15, 0.2 and 0.25%. From the experimental results it is observed that the optimum hybrid combination achieved at all fiber dosages is 75% PO + 25% PP. It is also observed that concrete reinforced with PO and PP hybrid fibers enhanced the tensile strength and toughness of the composite compared to mono-FRC for the same fiber volume fraction. The positive synergy between the non-metallic fibers drives to develop metallic and non-metallic HFRC.

The third phase of the investigation is carried out to develop the metallic and non-metallic HFRC with an aim to assess the strength properties and constitutive stress-strain behaviour. The developed HFRC can counteract the fracture process of concrete and achieve the overall performance of concrete in terms of strength, ductility and toughness. From the phase 2 experimental results, it is observed that non-metallic HFRC improved the tensile strength of the concrete but the improvement in toughness at post crack region is marginal. To increase the tensile strength and toughness at post-crack region, fiber hybridization is done using metallic and non-metallic fibers. Compressive strength, direct tensile strength, flexural strength and stress-strain behaviour under uni-axial stresses are studied. It is observed that Synergy effect was found to be more with the addition of metallic and non-metallic fibers due to inhibition of crack control at different stress levels. Results from the phase 3 have shown significant improvement on parameters like strength, ductility and toughness.

The fourth phase of the investigation consist of modelling of HFRC using ATENA software. Small prism of size 200 x 100 x 100 mm is modelled in ATEN to get the stress-strain curve analytically. The results obtained from the ATENA model are compared with the experimental values. The results shown good agreement with the experimental values within 15% variation. Later with the inputs from 200 x 100 x 100 model, flexure specimen of 500 x 100 x 100 model has been generated and analysed in ATENA. Results obtained from the flexure model are validated with experimental results. Experimental results and values obtained by the ATENA model is within 10% variation.

Overall the present study indicates that hybridisation of metallic and non-metallic fibers improved the properties of concrete with respect to tensile strength, flexural strength and toughness of the composite compared to mono-FRC and control mix for the same fiber volume fraction. Hence HFRC proven to be effective in resisting the cracks developed in concrete at all stress levels.

**CIVIL ENGINEERING**

Author : **SUDHEERKUMAR YANTRAPALLI**

Title of the thesis : **EVALUATION OF LOCALLY AVAILABLE CLAYEY**

**SOILS FOR THEIR SUITABILITY AS LANDFILL**

**LINERS**

Guide : **Dr. P. HARI KRISHNA**

Degree : **Ph. D.**

Student ID No. : **701336**

ABSTRACT

Indiscriminate and improper disposal of industrial as well as municipal solid/liquid wastes are highly responsible for the contamination of the soil and surrounding environment. In-order to minimise the contamination, researchers have developed various disposal methodologies such as solidification & immobilization, incineration, and land filling. Among these methods, landfilling is considered to be safe and cost effective method when compared to the rest. The efficiency of the engineered landfills highly depends on the hydraulic conductivity, sorption capacity and cracking intensity of the liner material. In general, the hydraulic conductivity of the liner material is considered as the main criterion for selecting the material and for designing the engineered landfill liner system. However, in addition to the hydraulic conductivity, sorption and cracking characteristics of the soils play a major role in preventing the transport of contaminants through the landfill liner system.

The presence of organic chemicals in the leachate influences the migration of heavy metals through the liner material. Among the various liner materials, compacted clay liner (CCL) is predominantly used in the landfills because of their low hydraulic conductivity and high sorption capacity. Formation of CCL requires large quantity of suitable soil as liner material. At present, in Warangal the biggest city of Telangana, the entire waste is disposed in an open dump yard in the out skirts of the city as there is no engineered landfill system, which is leading to lot of pollution in the surrounding areas. The general soil profile of this city consist of Black cotton soil and Red Earth of considerable thickness followed by murrum to very great depths.

In view of the above criteria, the two abundantly available local soils (Black cotton soil - CH, Red Earth - CI) were selected to evaluate their suitability as liner material based on the physical, sorption, breakthrough and cracking characteristics under the influence of organic chemicals. In the present study an organic chemical Ethylene Diamine Tetra Acetic Acid (EDTA) is used to understand the influence on the behaviour of clay liner. The sorption characteristics of these materials were established by conducting batch sorption and column flow experiments and the cracking characteristics were evaluated using image analysis criteria. Batch sorption studies have shown that, the adsorption of metal ions by both the soils increase with increase in pH of the heavy metal solution. In the presence of organic chemical (EDTA), the adsorption decreases with the increase in the pH for both the soils. The column flow studies have revealed that due to the multi metal (Pb, Ni, Cd and Cr) interaction, the diffusion of heavy metals increased when compared to the single metal interaction for both the soils. Due to the presence of organic chemical (EDTA) in the heavy metal solution, the diffusion characteristics of soils got further increased. The image analysis on cracked CH and CI soils indicate that, the crack intensity factor (CIF) is increasing with increase in water content and with the presence of heavy metal solution. The migration of heavy metals is observed to be more through both the soils due to the formation of cracks. However, the time to achieve breakthrough of heavy metals (Pb, Ni, Cd and Cr which are considered in the present study) through CH soil is more when compared to the CI soil. Among the four metals considered, chromium exhibited a different sorption behaviour when compared to other heavy metals due to its anionic form. In the presence of organic chemical EDTA, due to the formation of metal EDTA complex, there is an increase in the mobility of heavy metals through the soils.

The crack intensity factor is found to increase with the increase in compaction water content and number of wetting – drying cycles due to contaminants. Similarly, the value of permeability ratio (Kr) is observed to increase with the compaction water content. The range of increase in the permeability ratio is around 25% to 55% when the water content is increased from dry of optimum to wet of optimum. The diffusion of heavy metals through desiccated soils are in the range of 2.01 x 10-6 to 5.90 x 10-6 m2/sec for CH soil and 3.06 x 10-6 to 9.9 x 10-6 m2/sec for CI soil. From these studies, it is observed that the migration of heavy metals through CH soil is less when compared to CI soil. This is due to the fact that, CH soil is having good adsorption and more self-healing capacity when compared to CI soil. Based on the above observations, it can be concluded that, the locally available CH soil can be used more effectively as a compacted clay liner when compared to CI soil.

**Key Words:** Solid waste land fill, compacted clay liner, sorption studies, diffusion coefficient, crack intensity factor (CIF), permeability ratio (Kr)

**CIVIL ENGINEERING**

Author : **VEMU VENKATA PRAVEEN KUMAR**

Title of the thesis : **STUDY ON STRENGTH AND DURABILITY**

**CHARACTERISTICS OF LIME SLUDGE BASED**

**BLENDED CEMENT CONCRETE**

Guide : **Dr. D. RAVI PRASAD**

Degree : **Ph. D.**

Student ID No. : **714006**

ABSTRACT

Ordinary Portland Cement (OPC) is most conventionally used as the primary binder to produce concrete due to availability of the raw materials. The environmental issues associated with the production of OPC are well known, namely the amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuels. Concrete is one the most commonly used material in construction industry all over the world possessing good strength and durability characteristics. The increased demand for cement has led to huge emission of greenhouse gases. Production of 1 ton of cement is producing similar amount of CO2 which is about 5-7% of total carbon emission globally which is extremely hazardous and in turn leading to global warming. This figure is likely to increase even more in the coming decades. This is mainly because many developing countries are undergoing swift development in the infrastructure to meet the increased demand for growing population. To meet the increased demand of infrastructure, necessity of production of concrete using natural materials also increased which is the main reason for carbon footprint. The use of Supplementary Cementitious Materials (SCMs) in blended concrete can reduce the amount of CO2 into the atmosphere and also sustainability can be maintained (Imbabi et al. 2012). In Recent times, SCMs and their use in blended concrete receiving great attention all over the world. Blended concrete using SCMs have economic and performance benefits compared to conventional concrete. Many supplementary cementitious materials (SCM’s) like fly ash, silica fume, slag cement, rice husk ash, metakaolin, palm oil fuel ash are being used extensively but less attention is given on the use of Lime Sludge in concrete and its suitability. Keeping these issues in mind the present investigation is carried out on the utilization of lime sludge as one of the supplementary cementitious material with other mineral admixtures in blended cement concrete.

Based on the available literature, it was noticed that lot of researchers have focused on supplementary cementitious materials in order to reduce the consumption of cement content in concrete and to replace it with other suitable materials. Strength and durability were the parameters determined by many researchers using supplementary cementitious materials, where as to understand the materials in structural applications, there is a definite need to understand complete behaviour of materials in concrete using fly ash, silica fume and lime sludge. In addition to strength and durability, constitutive stress strain relationship and moment curvature relations are investigated in the present study.

Firstly, lime sludge was procured from nearby paper industry and the physical tests, chemical analysis and SEM analysis was performed on it. After obtaining the chemical composition of Lime sludge, suitability of lime sludge in preparing the concrete is verified by partially replacing cement by the sludge from 0-30% at an interval of 10% in three different grades of concrete. Total specimens cast for this is 72 cubes of standard size 150 X 150 X 150 mm size, 72 cylinders of standard size 150 mm diameter and 300 mm height and 36 prisms of standard size 500 X 100 X 100 mm. Mechanical properties such as compressive, split tensile and flexural strength at 7 and 28 days were evaluated for lime sludge based concrete and compared it with control mix .The results indicated the beneficiary effect of lime sludge as a partial replacement of cement due to the presence of high calcium content. Further the investigation is carried out in preparing blended concrete.

The investigation then focused on developing ternary blended cement concrete mix of different grades 30MPa, 50MPa and 70MPa containing fly ash, silica fume and lime sludge in different proportions to evaluate its mechanical and durability properties. The mineral admixtures used in the investigation were optimized consecutively. Firstly, experimental investigation was carried out to find out the optimum content of fly ash at different cement replacement levels of 5%, 10%, 15%, 20% and 25%. With the optimal dosage of fly ash, a binary mix is developed using fly ash and by replacing cement at different levels of 0, 4%, 6%, 8%, 10% of silica fume and then with the obtained optimum contents of fly ash and silica fume, ternary blended cement concrete mix is developed with fly ash (FA), silica fume (SF) and lime sludge (LS) as replacement to cement at different levels of 5%, 10%, 15% and 20%. In order to determine the optimum contents of mineral admixtures such as fly ash, silica fume and lime sludge with the presence of cement and to develop ternary blended cement concrete mix, a total of 144 cubes of size 150 x 150 x 150 mm were cast, water cured for 28 days and tested.

Durability is one of the most important aspects to be verified for any concrete and the same was performed on the established ternary blended cement concrete specimens and comparison was done with control mix specimens using OPC.

In the current investigation the following parameters were evaluated such as cumulative sorpitivity coefficient, acid mass loss factor (AMLF), acid strength loss factor (ASLF) and acid durability factor (ADF) in HCl and H2SO4 concentration of 5% along with advanced techniques for evaluation of chloride attack on concrete specimens like Rapid Chlorination Penetration Test (RCPT) performed on the optimum dosages of Ternary blended mix and compared with control mix to evaluate the durability characteristics. Sorpitivity coefficient was determined by casting 18 cubes of standard size 150 X 150 X 150 mm and placing them in water tubs. The results indicated the blended cement concrete mixes were having lower sorpitivity values compared to control mix indicating the impermeable nature of concrete specimens due to the presence of these mineral admixtures.

Acid mass loss factor and acid strength loss factor were determined at 7, 28 and 56 days by casting 108 cubes of standard size 150 X 150 X 150 mm immersed in 5% concentration HCl and H2SO4 solution. Mass and strength of the concrete specimens was measured initially before the placement of specimens in acid tubs and mass of specimens was measured after the exposure periods. The comparison of concrete specimens was performed before and after the exposure period and thus acid mass loss factor and strength loss factor are determined. The results inferred that the ternary blended cement concrete specimens have shown better resistance in an acidic environment compared to control mix specimens for all the grades investigated.

Chloride ion penetration into the ternary blended cement concrete and control mix concrete specimens was performed by rapid chlorination penetration test. Blended cement concrete specimens were superior compared to control mix specimens as the current passed into the specimens was lower compared to control mix.

Accelerated corrosion penetration test was also performed by casting cylinders of size 100 mm diameter and 200 mm height with a steel reinforcement rod of 8 mm diameter placed exactly at the centre. The results inferred that the blended cement concrete performed superior compared to control mix.

Constitutive stress strain characteristics of ternary blended cement concrete mix and control mix were performed by casting and testing cylinder specimens. The results indicated that the peak stress and the strain carrying capacity corresponding to peak stress of blended cement concrete specimens was higher compared to control mix specimens. It is evident, that the inclusion of these mineral admixtures as a partial replacement of cement has shown better performance compared to control mix.

Experimental moment curvature relationship was also investigated with the optimized contents of mineral admixtures and compared with control mix specimens. A total of 12 singly reinforced concrete beams of size 1800 mm X 100 mm X 200 mm were designed, cast and tested. The results indicated that there is a beneficial effect of mineral additives. There is a considerable increase in moment carrying capacity and corresponding curvature of ternary blended reinforced cement concrete beams compared with control mix specimens. The validation of experimental moment curvature relationship was performed using finite element method based software ATENA. The moment and curvature values obtained through modelling were in good agreement with the experimental results.

**CIVIL ENGINEERING**

Author : **VILLURI MAHALAKSHMI NAIDU**

Title of the thesis : **MODELLING TRIP GENERATION RATES FOR INDIAN**

**CITIES**

Guide : Dr.**C. S. R. K. Prasad**

Degree : **Ph. D.**

Student ID No. : **701130**

ABSTRACT

In this modern world where everything is becoming smart, there is a great need for the trip forecasting to catch up with the transportation planning. Cities across the world are growing in terms of their urban area and in number. Every city has its travel demand based on its socio-economic and land use characteristics. Number of trips generated in a day per person in a city is considered as Trip Rate. **In this work, trip generation rate, Per Capita Trip Rate are synonymous with the word Trip Rate.**

Present transportation planning models are prepared for estimation of cross-sectional data, hence are referred to as cross-sectional demand models. These works have demonstrated the theoretical and practical significance of developing travel demand models based on panel data (Kitamura 1988; Kitamura 1990; Meurs 1990; Goodwin et al. 1987; Michael et al. 2002 and 2006). Residential trip rates are underreported by the residents, especially trips that are not made with consistency. Retail trips are probably underreported than trips for work purpose (Reid 1982; Kumar et al. 1993). Modelling of small urban regions using single internal trip purpose was carried out by Anderson (2001).

Yam et al. (2000) formulated a multi linear regression model to assess traffic generation to high density, large scale, multi-story public residential accommodation estates in Hong Kong. The cross-classification analysis is more universally adopted (McNally 2000) with applications in passenger travel (Guevara et al. 2007) and also freight (Bastida et al. 2009). Even though, there were various attempts in the field of trip generation, quick estimates of trip generation rates for developing countries has become a field of rare focus. Keeping this in view, trip generation rate estimation process is studied for a developing country like India.

Trip generation studies include Cross-classification, Linear Regression, count data and neural network techniques. However, there is requirement for advancement in this matter. Instant estimation of trip generation rates for developing countries is required. Hence, this research work is taken up.

Parameters related to socio-economic status and land use were considered in the study. It is found that trip rate varies with power function, trip length varies linearly with respect to population of the city. Both these parameters vary exponentially with population density. For combined data, City Population and Industrial Area (%) are found to be having a logical sign, and population parameter is found to be most significant in the trip rate model. Cities were categorized based on population and area. Cities are categorized based on the population as CP1 (Population <10 Lakhs), CP2 (Population: 10-40 Lakhs) and CP3 (Population >40 Lakhs). Cities are categorized based on the Area as CA1 (Area <300 sq.km), CA2 (Area: 300-1000 sq.km) and CA3 (Area >1000 sq.km). Regression models were developed for these categories. Regression models were developed for combined cities and categorized cities data. As multiple parameters are available, the Principal Component Analysis (PCA) is used to reduce the dimensionality. Combined data (Socio-economic and Land-Use) is processed to get principal components. Better regression models were developed for the data of all the cities with principal components.

Data was processed through Artificial Neural Network (ANN) for trip rate prediction. For accurate prediction of trip rate, ANN has been applied. The Artificial neural network analysis with same data (Socio-economic and Land-Use) was employed. Performance of these models using ANN is found to be better than the performance of corresponding regression models. Various sets of Nomograms were developed to assess the trip rate using different input variables for all the city categories considered. PyNomo, sub-module of Python program was used for developing Nomograms. For all categories of cities, various Nomograms were developed with single and two input variables.

Trip rate increase with population size and this increase is steep up to a population of 40 lakhs. There is an abrupt change around 40 lakhs and increase in trip rate is found to be nominal, beyond 40 lakh population. The trip length of the city increases with the increase in population size. Regression analysis revealed that city population is found to be the significant variable in explaining Trip Rate. The training function TRAINLM has performed perfectly using the Feed Forward Back Propagation algorithm producing a predicted trip rate value. Principal Components with Artificial Neural Network arrangement models yielded superior correlation coefficient.