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GEMS OF STRUCTURAL ENGINEERING

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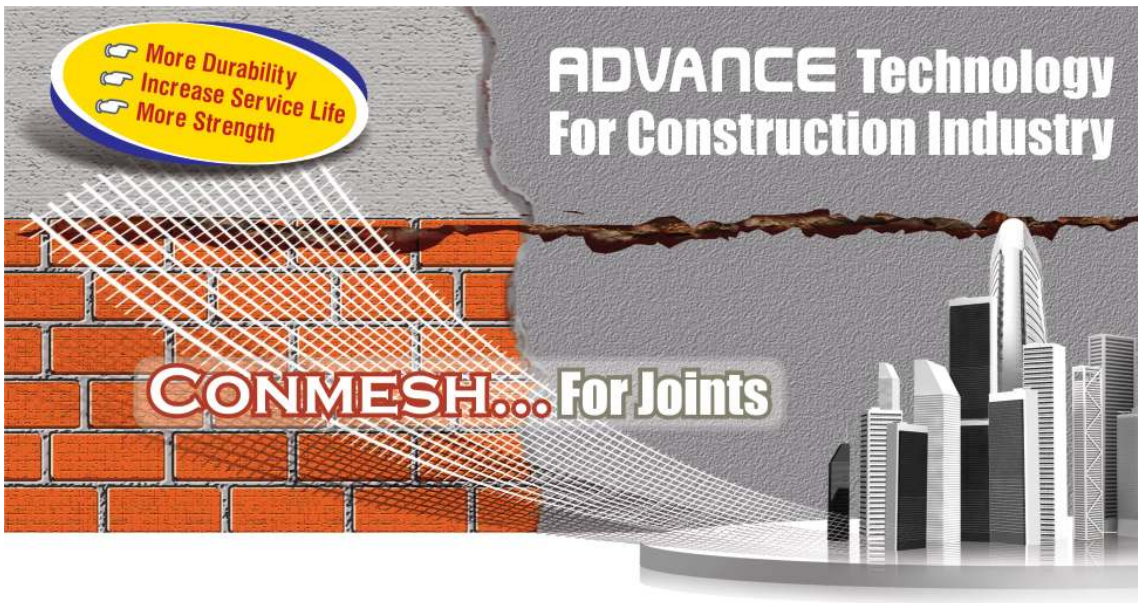

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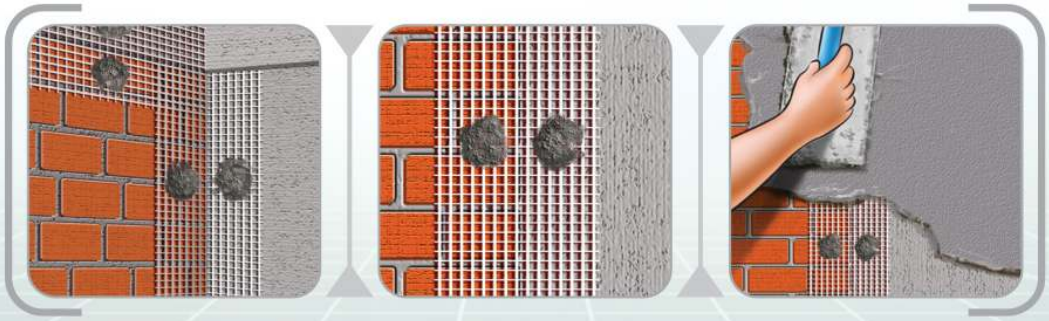

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GEMS OF STRUCTURAL ENGINEERING

GEM.6 – BHARAT RATNA SIR MOKSHAGUNDAM VISVESVARAYA

Dr. N. Subramanian and Er. Vivek G. Abhyankar

Sept. 15, 1860 - Apr. 14, 1962

Recently we celebrated Engineers' day in India on 15th September in the memory of Sir Mokshagundam Visvesvaraya; on that day we decided to write on Sir MV in the forthcoming issue. Sir Mokshagundam Visvesvaraya (popularly known as Sir. MV) is considered as a Father of Industrial Engineering in India. He was an Indian engineer, scholar, statesman and the Diwan of Mysore from 1912 to 1918. He is a recipient of the Indian Republic's highest honour, the Bharat Ratna, in 1955. He was knighted as a Knight Commander of the British Indian Empire (KCIE) by King George V for his contributions to the public good. He is held in high regard as a pre-eminent engineer of India. He was the chief engineer responsible for the construction of the Krishna Raja Sagara dam in Mysore as well as the chief designer of the flood protection system for the city of Hyderabad. By education he was a Civil Engineer, but by virtue of his abilities he was able to work in the entire gamut of engineering and performed beyond it in terms of financial growth of engineering sector in India. The structures planned and constructed by Sir MV are standing intact since past many decades. Present article is a small tribute to this great engineer.

Introduction, Early life

Fig. 1 Sir. Visvesvaraya at young age

Visvesvaraya was born on 15 September 1860, into a Mulukanadu Brahmin (Smartha Brahmins) to Mokshagundam Srinivasa Shastry and Venkatalakshmamma in Muddenahalli village, Chickkaballapur District, (Bifurcated from Kolar District) 96 km from Bangalore, Mysore State (now Karnataka), India. His father was a Sanskrit scholar and an authority on Hindu Dharmashastras (theology), besides being an Ayurvedic practitioner. At a very tender age of 12, he lost his father; the family was in Kurnool when this happened. Hence, his mother took him to maternal home at Muddenahalli, where little Visvesvaraya had to struggle hard to get education. But being inelegant he never found studies as a problem. He enrolled for primary school in Chikballapur and attended high school in Bangalore. Visvesvaraya learnt disciplined life since childhood days itself. He completed B.A. from Central College Bangalore, then affiliate of the University of Madras in 1881. Then Visvesvaraya completed engineering studies from Poona Science College in 1883 and completed L.C.E. and E.C.E.L engineering exams at the age of 23; he stood first within entire Mumbai region.

Career as an engineer

After completion of education in engineering he started his career in the year 1884 as Assistant Engineer in Public works Department (PWD) of Mumbai Government, and was later invited to join the Indian Irrigation Commission. He served the Mumbai Govt. for 23 years. Due to his efforts the administration of rail-routes from Birur to Shimoga, Mysore to Nanjangud, Bangalore to Mysore, he was transferred to Mysore Government. He was elevated as the Chief Engineer of Mysore Government on November 15, 1909, as per his plans. In 1912, he became the Diwan of Mysore. As a Member of the Indian Irrigation Commission, he implemented an extremely intricate system of irrigation in the Deccan area.

Sir MV had designed and patented a system of automatic weir water floodgates that were first installed in 1903 at the Khadakvasla Reservoir near Pune. These gates were employed to raise the flood supply level of storage in the reservoir to the highest level likely to be attained without causing any damage to the dam. Based on the success of these gates, the same system was installed at the Tigra Dam in Gwalior and the Krishna Raja Sagara (KRS) Dam in Mandya/Mysore, Karnataka. But the success did not come to him easily, as he had to struggle hard and establish his hard work and dedication before the British authorities working on this project.

In 1906–07, the government of India sent him to Aden, Egypt to study their water supply and drainage system. The project prepared by him was implemented in Aden successfully.

Visvesvaraya achieved celebrity status when he designed a flood protection system for the city of Hyderabad. He was instrumental in developing a system to protect Visakhapatnam port from sea erosion. Visvesvaraya supervised the construction of the Krishna Raja Sagara (KRS) Dam across the Kaveri River from concept to inauguration (1911-31). The dam is named for the then ruler of the Mysore Kingdom, Krishnaraja Wodeyar IV. This dam created the biggest reservoir in Asia when it was built and one of the biggest dams in India. The dam is fully functional even today. There is an ornamental garden attached to the dam, called Brindavan Gardens, planned and built by Diwan Sir Mirza Ismail of Mysore, which spreads across an area of 60 acres (started in the year 1927 and completed in 1932).
Krishna Raja Sagara reservoir was formed by the construction of a dam across the Kaveri river, 9 miles on the upstream side of the historic town of

Srirangapatna and 12 miles from Mysore City. The lake, at the maximum water level, has a water spread of both 130 sq. km. In the words of Sir MV, the scheme was to “open out a vista of possibilities of ever-increasing value in the state by adding to the productive power of the people with the increase in agricultural produce and development of industries and manufacture”. The catchment area of the river above the dam is 1.4 km^3, half of which lies in the regions of Coorg and Mysore Districts. The reservoir ensures a steady supply of water for the generating station at Shivanasamudram Shimsa, enabling power supply to the Gold mines at Kolar, and electric light and power supply to the cities of Bangalore and Mysore, besides a large number of villages and towns in the state. The reservoir is the main source of drinking water for all of Mysore city and almost the whole of Bengaluru city, the capital of the state of Karnataka. The water released from this dam is further used as an important source of water in the state of Tamil Nadu, which has its own Mettur dam in the Salem district.

Fig.2 Krishna Raja Sagara Dam and Brindavan Garden

Sir MV was called the "Father of modern Mysore state" (now Karnataka): During his service with the government of Mysore state, he was responsible for the founding of (under the patronage of the Mysore government) the Mysore Soap Factory, the Parasitoide Laboratory, the Mysore Iron & Steel Works (now known as Visvesvaraya Iron and Steel Limited) in Bhadravathi, the Sri Jayachamarajendra Polytechnic Institute, the Bangalore Agricultural University, the State Bank of Mysore, The Century Club, Mysore Chambers of Commerce, University Visvesvaraya College of Engineering, Bangalore and numerous other industrial ventures. He encouraged private investment in industry during his tenure as Diwan of Mysore. He was instrumental in charting out the plan for road construction between Tirumala and Tirupati. He was known for sincerity, time management and dedication to a cause.

Fig.3 Visvesvaraya Iron and Steel Limited in Bhadravathi

Fig.4 The State Bank of Mysore's head office in Bangalore

Fig. 5 University Visvesvaraya College of Engineering

Fig. 6 Sri Jayachamarajendra Polytechnic Institute

In 1913, Mysore-Hassan-Arsikere rail-route work was started. In 1914, mechanical engineering school at Bangalore was started. On the 22nd of July, 1916, the Mysore University was started. The Mysore soap factory and the Sandalwood factory was also started during this period. On 9-12-1918 he gave resignation from Diwanship. In 1943, he was responsible for opening of the Jaya Chamarajendra Technical Institute at Bangalore.

When Mandya District was brought under assured irrigation consequent to the construction of the Vishveswariah Canal, the Government of Mysore recognised that the prosperity of the region would depend in a large measure on the profitable cultivation of a commercial crop like sugar cane and that this would be possible only if manufacture of sugar on modern lines was initiated on a fairly large-scale. The sugar industry being in the nature of a new industrial venture and capital being shy in those days, the then Government of Mysore took the initiative to float a joint stock company, as an earnest attempt in the welfare of the agriculturists on one hand and to infuse confidence in the minds of the investing public on the other. Thus, the Mysore Sugar Company came into existence in January 1933 with an authorised capital of Rs. 20 lakhs, of which 60 percent was taken by Government. This pattern of company formation with the Government holding a majority of shares was a novel one and may well be said to be the fore-runner of the present day public sector companies. The sugar factory at Mandya is one of the biggest industrial units in the state.

Accolades for Sir MV

Fig. 7 With the then Prime Minister Jawaharlal Nehru

Sir M.V. had earned a reputation for his honesty, integrity, ability and intelligence. He had introduced compulsory education in the State which later was embodied as a fundamental right in the Constitution of independent India. Sir MV was patriotic, hard working, highly disciplined and an able administrator.

Sir M.V. was never interested in fame or publicity. But they came to him on their own. Every university in India sought him out to confer honor in cause

(the university of Allahabad, Andhra, Bombay, Calcutta, Jadhavpur, Mysore, Patna and Varanasi). The various books / booklets / reports published by Sir. MV during his period contain his noble thoughts as well as depict the status of Indian society in those days. Unfortunately today a very few of his reports are available for reference. Sir MV could live a long life only because of disciplined living, he followed all Indian cultural protocols and diet routines. During his visit to various western countries, he wrote, “In Europe I lived a life completely like an Indian Sage, by eating fruits and drinking milk”!

Fig.8 Sir M Visvesvaraya on his 99th birthday on September 15, 1959 with then chief minister of Mysore B D Jatti

Sir. MV received many awards, including the highest award of 'Bharat Ratna', 'The Knight Commander of The Indian Emperor', honorary Doctorate degrees, which are listed below.

Fig. 9 Two Medals awarded to Sir M Visvesvaraya

Fig. 10 (Up) Sir. MV received Bharat Ratna Award from the then President Dr. Rajendra Prasad, (Down) Sir MV received another award from the then Prime Minister Shri. Jawaharlal Nehru

Awards Received by Sir MV :-

1. 1904: Honorary Membership of London Institution of Civil Engineers for an unbroken period of 50 years
2. 1906 – "Kaisar-i-Hind" in recognition of his services.
3. 1911 – C.I.E. (Companion of the Indian Empire) at the Delhi Durbar
4. 1915 – K.C.I.E (Knight Commander of the Order of the Indian Empire)
5. 1921 – D.Sc. – Calcutta University
6. 1931: LLD – Bombay University
7. 1937: D.Litt – Benaras Hindu University
8. 1943: Elected as an Honorary Life Member of the Institution of Engineers (India) 1944 – D.Sc. - Allahabad
9. 1944: D.Sc. – Allahabad University
10. 1948 – Doctorate – LLD. Mysore University.
11. 1953 – D.Litt – Andhra University.
12. 1953 – Awarded the Honorary Fellowship of the Institute of Town Planners, India.
13. 1955 – Conferred BHARATH RATNA–
14. 1958 – 'Durga Prasad Khaitan Memorial Gold Medal' by the Royal Asiatic Society Council of Bengal.
15. 1959: Fellowship of the Indian Institute of Science, Bangalore

Fig. 11 Sir. MV with his close family and friends, a rare photograph

Books composed by Sir MV

1) Constructing India, 1920.
2) Rural Industrialisation in India, 1931.
3) Unemployment in India : it's causes and cure, 1932.
4) Planned Economy for India, 1934.
5) Nation Building: a five year plan for the provinces, 1937.
6) District Development Scheme, 1939.
7) Prosperity through Industry, 1942.
8) Village industrialisation, 1945.
9) Memories of my working life, 1951.
10) A brief memory of my complete working Life, 1959.

Sir M. Visveswaraya published a number of reports on Engineering designs, works on technical education and on economic developments. Above are some of his more important publications. He had also published several pamphlets on industries and the same were issued through the all India Manufacturers" Organization, Bombay such as:

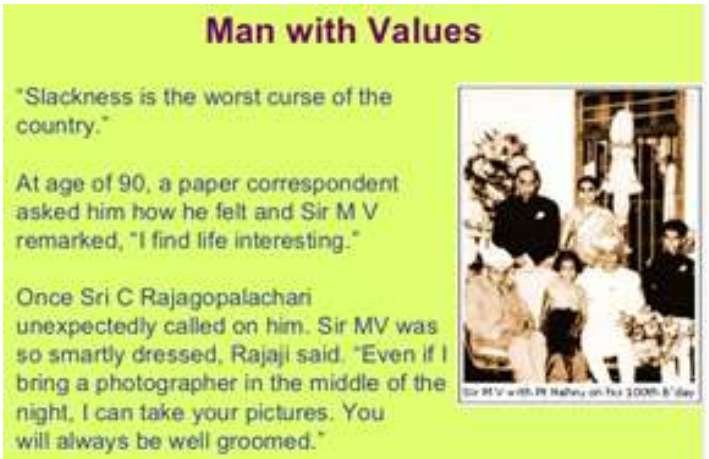
a) District Industrialization Drive
b) Reconstruction in Post war India
c) Development of Heavy Industries in India
d) Industrialization scheme for Rural Areas
e) Industrialization scheme in two parts
f) Village Industries Hand Books

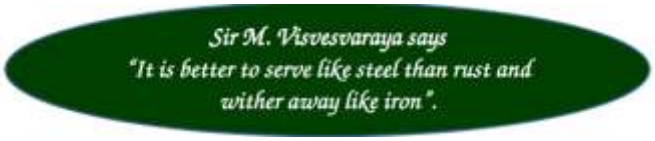
In addition to the above, he had issued a large number of small publications pamphlets and reports on engineering, economic, industrial and other related topics. After the death of Sir MV a Science museum was established in Bangalore in his memory. The Visvesvaraya National Memorial Trust also manages a memorial of Visvesvaraya at his birthplace Muddenahalli. The memorial exhibits his awards, titles and personal belongings, including his living room, spectacles, cups, his copy of the Webster's dictionary, and a block with which his visiting cards were printed. Models of the Krishna Raja Sagara dam, which Visvesvaraya designed and supervised, and its construction are also exhibited. The memorial is located adjacent to his house, which was

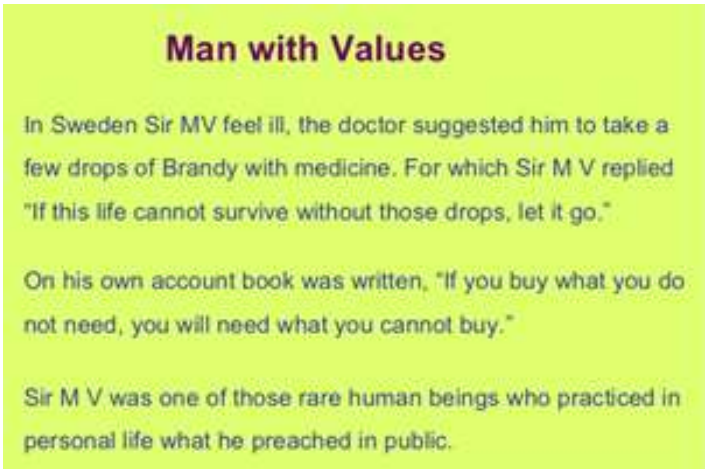
refurbished and regarded as a temple by the locals. Frankly spoken, his work is endless and difficult to cover in a few pages; we advice readers to read his detailed biography and available literature, for further information. However, we hope that the present short article will inspire readers (especially young engineers) to learn more about him and his works.

Fig. 12 Visvesvaraya Science Museum, Bangalore

Famous Sentences of Sir MV







Sir.M.V.died on April 14, 1962 at the age of 102 years, 6 months and 8 days. As per his wish, hewas cremated in his birth place, Muddenahalli**.**

Fig. 13 The Samadhi of Sir M.V. at Muddenahalli

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Dr. N. Subramanian, is a Civil / structural consultant (currently based at Maryland, USA) with over 40 years of experience in Industry (including consultancy, research and teaching); former CEO of Computer Design Consultants, India, and Director of Computer Technological Institute, author of 200 technical papers and 25 books, is an asset for the field of structural engineering. The books on Design of Steel Structures by Limit State Method, Design of Reinforced Concrete Structures and Space Structures were the most popular books of Dr. Subramanian. He was awarded with a 'Life Time Achievement Award' and many other awards for his contribution towards Structural Engineering.

Er. Vivek G. Abhyankar – C.Eng (Ind), Sr. Manger (Design), AFCONS Infrastructure limited, has more than fifteen years of experience in planning and design, detailing of various enabling and permanent works in Reinforced concrete and Steel. Life member of various Institutes, professional trainer, ISO-9001 Auditor, author of a couple of Technical report and was involved in the making of a famous book on RCC design for earthquake engineering, published by ISSE. He was also a visiting faculty for Graduate and Post-Graduate students in Structural engineering at VJTI.

REPORT ON STRUCTURAL AUDIT SEMINAR HELD ON 21 NOV 2015 AT DOMBIVLI.

It was realised that all the technical lectures are conducted in Mumbai. Kalyan Dombivali area is deprived of such seminars. Rotary club of Dombivli Saudamini , jointly with ISSE, organised a seminar on ,"Structural Audit and Repairs, " in Dombivali, on 21 Nov 2015.

President of Rotary club of Dombivali Saudamini, Kirty Vadalkar gave the club's thinking behind organising such a seminar. She said, people at large, are unaware of the role of Structural Engineers, in the building process. They also do not consult one while going through interior design. The municipal corporation serves a notice of Structural Audit, and nobody knows what to do, whom to contact. In this area there are fewer structural engineers, and common citizens have the least of idea about structural audit. They even do not know about who is authorised to conduct it. The idea to organise the seminar was to spread awareness.

Structural audit is made mandatory for all the co-operative housing society building structures which are more than 15 years old. The residents don't bother about the condition of the structure, rather they are not much aware about the safety of the building due to unauthorised alterations to the structural elements.

Once they take possession from the builder, they contact a local interior designer who may not be necessarily a qualified person to carry out the job. But no body bothers to find out the hidden dangers. Suddenly , somewhere there is a building collapse, and everyone gets up to search for the reasons. Its just a temporary phase, with passage of time, everything comes back to the same stage.
Er Shantilal Jain, senior structural engineer, past president Institution of engineers and advisory trustee of ISSE, spoke on behalf of ISSE.

He narrated the work of ISSE and how important it is to consult a Structural Engineer in case of all repairs and renovations. He emphasised the need for spreading the awareness among masses. He also felt that more and more such sessions be conducted all over. He welcomed the idea and assured all support.

Er Jain narrated the incidents in the past , where unnecessarily a structural engineer was held responsible for no fault of his. He also informed the audience about the efforts by ISSE to prepare a standard draft report of structural audit.

Er Hemant Vadalkar, senior structural consultant and advisory trustee of ISSE, was the next speaker. He gave the in depth knowledge of the process of structural audit. He began with what it means by auditing a structure. He said people are aware of financial audit , they also go through a regular health audit. Structural audit is for assessing the health of the structure. This is essential to find out the present condition of the structure. So in reality, it is the present day status check of the structure.

People appreciated when he correlated the structures with the human body.

He then gave the details to be covered by the auditor while conducting the audit process. He also emphasised on the contents of the report.
Though, an expert may know what all to do while going through the audit process, there are practical difficulties. The false ceilings hide the conditions of the beams. The decorations do not allow to reach up to the columns. The society does not have original papers. No original plans are not available for review. So, to assess the condition of the structure becomes very difficult.

If a builder wants to redevelop a building, he wants structural audit report to indicate a dilapidated building which needs demolition. If the tenants of a building approach for structural audit , they expect that the report should mention that the building is in

good condition and they should not be evacuated by the authorities by declaring the building as unsafe.

He emphasised that the auditors should be rational in their approach and must give true report based on the actual facts.

Er Arun Kelkar has written a book on Building Structural audit and repairs. He discussed the contents of his book on the same subject. He discussed the flow chart of how to conduct a structural audit and guidance for society members for carrying out repairs.

Er Anil Lad , Deputy commissioner, KDMC, a highly qualified person with variety of degrees to his credit, and an expert in the legal matters, pertaining the corporation.

He discussed the legal provisions for Structural Audit, laid out by the Maharashtra Government and Municipal corporations. It is absolutely essential for everyone to know the law and provisions thereof with respect to the structural audit. Commoners don't have the slightest of the idea. He narrated that it is not a burden for the citizens but a boon as it will prevent any serious mishap. He discussed all the provisions, like the person who is qualified to do the job, when , how, contents of the report, powers of commissioners to get the audit and repairs done and then charges can be recovered from to Co-operative housing society and so on.

Er Madhav Chikodi, narrated his experiences in conducting structural audit.

He said a commonly asked question is what is the life of the building and whether we get double area after redevelopment ? People never negotiate fees with a medical practitioner but they do a lot of negotiation on the fees to be paid to structural engineer for audit. At times people think that they can go to another person with a lesser fees just to get the certificate. He shared his experience in carrying out structural audit for 250+ buildings in KDMC area which was interesting.

Manjusha Seludkar proposed vote of thanks. And discussed the importance of the seminar. The program was compered by Prajakta Thali.
The Seminar was free for all. Program was appreciated by the attendee. There were many registrations, but due to heavy rains, the attendance was about 60.

Photographs of the event 21 Nov 2015 (Structural Audit at Dombivli)


ब्राह्मण सभा
Shantilal Jain
Structural Audit -21 Nov 2015


ब्राह्मण सभा
Anil Lad - Dy. Municipal Commissioner KDMC
Structurl Audit -21 Nov 2015


ब्राह्मण सभा
Hemant Vadalkar
Structural Audit - 21 Nov 2015


ब्राह्मण सभा
Madhav Chikodi - Consulting Engineer
Structural Audit -21 Nov 2015


ब्राह्मण सभा
Arun Kelkar - Structural
Audit 21 Nov 2015

APPLICATIONS OF TENSILE STRUCTURES

Vedang Vadalkar and others.

ABSTRACT

Tensile structures are gaining popularity due to their light weight, structural efficiency, serviceability, aesthetic appearance, and ease of installation and dismantling of elements. These structures satisfy both, the architect's design of attractive elevation as well as considerably reduce the dead weight making the overall design more economical. Every part of structure is loaded only in tension with no requirement to resist bending or compression. In order to eliminate the compressive forces in these structures, they are pre-stressed to the extent that they are stable even after the application of external loads. They can be used at various public areas like airport, boat docks, sport areas, public bus stops, car parking, and exhibition centers for the purpose of providing large areas with column free spaces. They can also be used as a replacement for glass cladding in buildings. They exhibit non-linear behavior due to both geometry and material effect. This dissertation examines a variety of different factors concerning these membrane structures.

INTRODUCTION

Much of society is unaware of the detailed specification behind the Tensile structures. It is important to be aware of safety issues when utilizing these structures. Unlike traditional structures, membrane type structures are primarily under tension and have characteristics that set them apart from other forms as the load applied to the surface must be resisted by tensile stresses in the membrane. In order to ensure that stresses remain within acceptable limits, it is usually desirable to establish initial curvature in the membrane. This requires that the membrane be placed in state of internal stress or pre-stress. Fabric membranes are selected for a given structure based upon their strength, durability, fire performance, optical properties, and finish.

ARCHITECTURE

Most architectural forms have developed from the nature of traditional building materials. Building forms that developed from a material, like masonry, are quite often built of other materials. These forms create an architectural vocabulary well understood by the general public. However, an architectural vernacular of membrane structures has yet to be established due to their recent development. As familiarity with tension membrane architecture increases, they will be employed more often for their architectural forms.

APPLICATIONS

A tensile structure can be thought of as an umbrella and create tension in different ways, depending on the size of the area that needs to be covered. The early traditional forms of these structures were tents. Innovative and structurally efficient tension membrane systems have been mostly employed for roofs. Not only as covering but they can also be used for the purpose of climate regulation and utilizing natural sources of light reducing the usage of non-renewable sources. In some applications, the roof is employed as the entire building envelope, but applications of tension membranes as enclosure material for walls alone remain a rare exception.

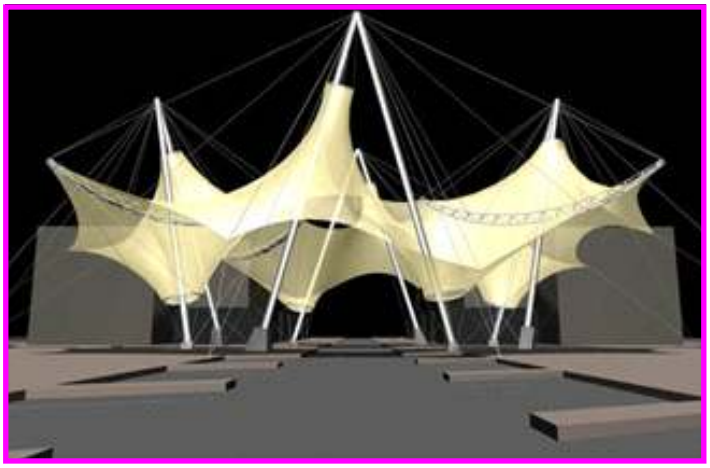

FIG-1 Conceptual design of a tensile structure.

MATERIALS THAT CAN BE EMPLOYED:

Fabric architecture can be explained under three main headings viz. coated fabrics, open meshes and foils.

COATED FABRICS	OPEN MESH	FOILS
Coated fabrics present a symmetrical structure of yarns arranged in two main orthogonal directions: warp and fill. While the structural function is mainly provided by the yarns the coating protects it from chemical and biological.	For applications which do not require weather tightness, the use of open mesh fabrics is recently becoming quite popular.	Architectural foils are widely used for pneumatic application. Reduced mechanical properties limit their use for large cushions and single skin envelopes

COATING

The final properties of a coated fabric, with the only exception of the mechanical performance, are mainly related to the materials used for the top coatings. Materials used for coating: PVC, Fluoropolymer Coating, Silicone, Polyurethane, Polyethylene, Synthetic Rubbers, Low E Coating

	PVC Coated polyester fabrics	PTFE Coated glass fabrics	Silicone coated glass fabrics	PTFE Coated PTFE fabric
Tensile strength (warp/weft) kn/m	115/102	124/100	107/105	84/80
Fabric Weight (gm/m^2)	1200 (type 3)	1200 (type G5)	1100	830
Trapezoidal tear warp/weft (N)	800/950	400/400	960/700	925/925
Visible Light transmission (%)	10-15	10-20	<80	19-38
Flexibility/crease recovery	High	Low	High	High
Fire reaction	M2 (NFP 92503) B1 (DIN 4102)	M1 (92 503) B1/A2 (DIN 4102)	A (ASTM E-108) no toxicity of smoke	
Cleaning	Easier at the top	Self cleansing	Self cleansing	Self cleansing
How to make the seams	High Frequency	Thermally	Vulcanisation	Stitching
Life span (years)	>15-20	>25	>25	>30
Cost	Low	High	High	High
Significance	a)Colourful and aesthetically pleasing. b)Ease for welding operations.	a)Large prestress hence greater support system. b)Sturdy and can resist harsh winds.	a)High resistance to chemicals and corrosion. b)High thermal insulative properties.	a)Low friction, hence ease of cleaning. b)High life expectancy.

INTERNAL ENVIORNNMENT

These membrane enclosures function both as load bearing structures and building envelope. Now a days the issue of resource scarcity applies not only to material but also to energy and here again these structures have a role to play. This utility function of these structures allows them to be used as replacements of glass claddings in commercial buildings. The fabric skin acts as passive filter capable of modifying both thermal light levels within the enclosed space to minimize the reliance on conventional energy sources.

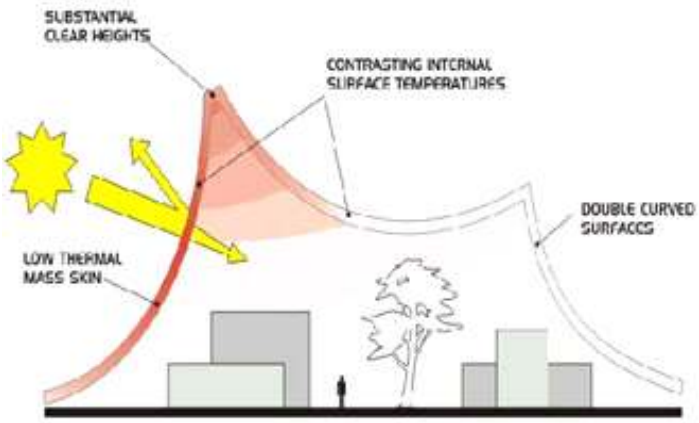

FIG-2 Enclosure

LOAD CONSIDERATIONS

Changes in loading conditions are likely to have larger impact on the size of the structural members required and the scale of deflections experienced. Membrane structures are usually 'compensated' so that the fabric will achieve the predefined pre-stress levels at the correct geometry once the creep of the membrane has occurred. Uplift Wind Pressure is the critical case for membrane and cable stresses in lightweight membrane structures. It is generally considered as a static load case, defined by a dynamic pressure multiplied by a pressure coefficient (Cp). Earthquake acceleration has no impact on these structures because of light weight.

THE DESIGN PROCESS

The initial shape of membrane structures is obtained by the process of “Form finding” which assures that each point of the surface is in equilibrium and verifies the warp and weft forces

arising into the fabric and also their compliance with the boundary conditions. The architectural and the structural idea should reach to a solution which is both aesthetically pleasing and structurally efficient and feasible. The design is completed based on the material properties and is reliant on the behavior of fabric under loading therefore the structural designers and manufacturers should be involved in the process from initial stages on design only. The design process basically follows three main steps: Form finding, static analysis and dynamic analysis.

FORMFINDING

The membrane configuration in the three dimensional space cannot be imposed without a prior design consideration and hence the final shape is an articulate membrane configuration obtained by accurate calibration of various parameters and the combination of basic shapes. According to Lewis (2003), Form finding may be defined in the following ways: “Finding the optimal shape of a tension membrane, finding the shape of the tension membrane that is in static equilibrium but doesn't have a constant surface stress, finding the shape which approximates the sate if full static equilibrium.” With computer-run numerical processes, the given pre-stress values and geometry calculate the forces induced at each element. To assist in aligning warp and fill directions with the principle curvature, a line is super-positioned over the model to trace the shortest distance between boundaries.

STATIC EQUILLIBRIUM

The initial curvature assumed in Form finding is further carried to do static analysis. This is basically done to keep a check on deflections that arise due to snow, rain and wind loads. The results are represented in a colored pattern showing various zones of critical sections showing stresses. The determination of stress distribution is a crucial step in the design process, since the membrane choice or the detail resistance depends on the maximum value noticed.

DYNAMIC ANALYSIS

The dynamic analysis evaluates the correlation between the fluctuating applied loads and the structure geometry. As the wind forces are the most critical forces, through the use of rigid models equipped with sensors of pressure, the wind force distribution on the rigid surface can be individuated, which reproduces, in scale, real environmental conditions. This approach aims to obtain the wind force distribution under significant boundary conditions which are the necessary input for simulating software.

PATTERNING

The fabrics used are unable to withstand prolonged shear loading. The layout should be thus made such that principle membrane stresses approximately coincides with fabric weave direction. Stretch compensations are induced. They would vary with the prestress ratios and level of warp and weft forces.

STRUCTURAL ADVANATAGES OVER OTHER CONVENTIONAL SYSTEMS

Tensile membrane structures provide a large variety of shapes and materials to be employed with good age and less maintenance costs. As compared to other space frame structures and conventional truss-roofing systems which require a lot of installation periods and face a lot of leakage and corrosion problems in their life spans, these structures are quick in installation and materials are so managed that possibilities of defects are minimized easily. The earthquake loads are not considered because of very less weight of structures and hence reduces the impacts when such natural calamities are witnessed as compared to space frames which may cause damage as steel has greater weight per meter values. The conventional trusses are not aesthetically pleasant are suspected to greater damages under critical loading conditions.

CASE STUDIES

1. D.Y. Patil Stadium, Mumbai.

The Stadium is built inside the DY Patil Vidyanagar campus. The DY Patil is at the moment the largest membrane roof in India. With all the essential ingredients to host internationals, the DY Patil Stadium boasts of 9 tennis hard courts, 4 indoor

badminton courts and an Olympic sized swimming pool, apart from big dressing rooms and a green outfield.

FIG-3 D Y Patil Stadium's roof, Navi Mumbai

A unique feature of the stadium is the cantilever membrane roof which eliminates the need for any supports thus providing the spectators with an unobstructed view of the match from any place within the stand. First requirement for this project was to design a cost effective stadium roof which shall be easy and faster to execute. Considering this issue, the selection of the material was very important. Hence, the customer decided to go for tensile structure for the stadium roof. 17m Cantilever roof trusses are designed with rear side tie supports in round pipes to have an uninterrupted view of the cricket ground and the spectators.

This sprawling stadium has a roof area of 9300 sq.mtrs. The profile and the placement of roof trusses is worked out in such a way that there will be no water logging on fabric as well as air escape will take place naturally to avoid up lift of wind. The use of tensile fabrics added an aesthetic value to the stadium roof as well as it has reduced the consumption of steel. The fabric used is PVDF Mehler Valmex FR1000 (Type III)

The shape of the membrane roof was developed in order to avoid any natural shadow on the playground whereas it also able to grants sun protection to 55000 spectators.

2. Khan Shatyr Entertainment Centre, in the Kazakh city of Astana

FIG-4 Khan Shatyr Centre illuminated at night

The tent-shaped Khan Shatyr Entertainment Center, the world's tallest tensile structure, designed by UK-based architectural design firm Foster + Partners, has been unveiled in Astana, Kazakhstan.

The Khan Shatyr Entertainment Center was officially opened on July 5, 2010. The huge transparent tent structure offers a new civic, cultural and social venue, bringing together a wide range of activities within a sheltered climatic envelope that provides a comfortable environment all year round.

The 150m-high tent-like structure has a 200m elliptical base covering 140,000 square meters. The tent contains an area larger than 10 football stadiums including an urban- scaled park; a host of entertainment and leisure facilities including retail, cafes, restaurants and cinemas; and flexible spaces that can accommodate a variety of events and exhibitions. The different levels form undulating terraces, with the uppermost terrace forming a water park.

The roof is constructed from Ethylene tetrafluoroethylene (ETFE) suspended on a network of cables strung from a central spire. Temperatures in Astana can drop to -35 degrees Celsius in winter and rise as high as +35 degrees in summer. The three-layer ETFE envelope is designed to shelter the enclosed accommodation from weather extremes and to allow daylight to wash the interiors.

In winter, a combination of temperature control and directing warm air currents up the inner surface of the fabric, helps in preventing the formation of ice on the inside of the envelope. This strategy also prevents downdraughts. In summer, fritting on the outermost foil layer provides solar shading. Low-level jets direct cool air across the space, while opening vents at the apex stimulate stack-effect ventilation.

3. Denver International Airport

Denver International Airport often referred to as DIA, is an airport in Denver, Colorado, United States. At 34,000 acres (53 sq mi), it is the largest airport in the United States by total land area Runway 16R/34L, with a length of 4,877 m, is the longest public use runway in the United States. As of 2014, DIA was the 18th-busiest airport in the world and the 5th busiest in the United States by passenger traffic with over 53 million passengers.

The Jeppesen Terminal's internationally recognized peaked roof, designed by Fentress Bradburn Architects, is reflective of snow-capped mountains and evokes the early history of Colorado when Native American teepees were located across the Great Plains. The Teflon-coated fiberglass roof of Denver International Airport resembles the Rocky Mountains The catenary steel cable system, similar to the Brooklyn Bridge design, supports the fabric roof. DIA is also known for a pedestrian bridge connecting the terminal to Concourse A that allows travelers to view planes taxiing beneath them and has views of the Rocky Mountains to the West and the high plains to the East.

FIG-5 Denver International Airport

CONCLUSION

The present study enlists the various factors concerning with tensile structures and explains various materials with their governing properties and also the basic design process. Various advantages are discussed over other structures to make society aware of the technological advantages of these structures which is done economically. These structures are aesthetically pleasing. These beautiful creations attract people's attention which can help in increasing tourism and in turn gaining economical benefits.

ACKNOWLEDGEMENTS

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USE OF FERROCASTING FOR HIGH VOLUME BUILDING CONSTRUCTION

Arun Purandare – Structural Consultant

Ferrocement use for architectural shapes has been in construction practice for more than 150 years. It was mainly preferred, where thin curved sections of concrete could not be easily cast. The method of making these sections was by hand plastering on steel meshes from both sides. The surfaces were later made smooth by plastering. The major use was in constructing circular water tanks and also making canoes and ships upto 20 mt length. The Ferro cement section showed very large tensile capacity. The material also exhibits large impact resistance. These properties were used in the making of structural forms.

The method of construction however, has inherent shortcomings with respect to quality assurance and non-consistent structural performance. This is due to the very nature of its construction system. The product is made by plastering manually. It leads to inconsistent mortar quality and strength. The dimensional accuracy also cannot be obtained. Small dimensional variation can be a large percentage variation in a section that is thin in size. This leads to uncertainty in structural performance of the section. These shortcomings were the main reason for not using this material and its unacceptability in building construction.

Large numbers of research papers are available, numbering in thousands, on various issues of ferro concrete sections in compression, tension and shear. In spite of their body of research, ACI Committee 549 decided not to give stress values for design in bending and compression. However values that can be achieved and conditions under which they are observed is given. This negative recommendation was mainly due to the hand plastering method of construction. One can compare it with hand mixing not being allowed in structural concrete.

The approach of ACI Committee was discussed with Prof. Dr. Balaguru, who chaired the committee, and its recommendations. A method of casting the sections was devised and experiments, as suggested, were conducted to confirm stress values. Article describing the various experiments would follow this article in the next issue of the journal.

The proposed sections were cast in steel moulds with weld meshes of sizes and numbers as per recommendations of the ACI guidelines. The design stresses were taken from those obtained in the experimental work, Special mix design was made to get M-30 compressive strength of the mortar. As the demoulding was done in 7/8 hours after casting, the minimum strength obtained was 12 Mpa for shifting the casting to curing yard without damage. This helps in casting two times in a day, in a period of 10 hours. This doubles the productivity of the casting yard and brings down the cost of individual units. The production per day also doubles.

Two projects are described in which the building elements were made; (i) with hand plastering & (ii) by casting in moulds.

1. Dr. D.Y.Patil Engineering College at Talegaon

During construction of the G +8 building , it was decided to construct the 5th floor with Ferro cement elements. 15,000 sq ft of area was designed with hand plastered columns, slabs and beams (Fig 1 & Figs 2 & 3). They were also used as Lost Form Shuttering. Topping concrete had continuity reinforcement over the support along with additional reinforcement for positive bending movement at the centre of the span. The sections took a long time to form and left much to be desired with respect to the plastering quality and dimensional accuracy. After plastering the concrete surfaces, no defect could be seen (Fig4). The total process took 4 months and a lot of labour input.

Fig. No. 1 : Column Tube

Fig. No. 2 : Plastering Beam

Fig.No. 3 : Lifting of Beam

Fig. No. 4 : Plastering Slab

2. Experimental Room at Pirangut

Columns, beams and slab ferrocas units of were made with 25mm wall thickness for column and 20 mm wall thickness for beams and slabs. Two layers of 1.5mm diameter wire meshes with square opening were used. The mortar mix was M-30. All sections were cast in steel moulds (Fig 5). The beams and slabs were designed as ferrocast material with a cracking tensile stress of 24 Mpa. As obtained in experiments. The design was done in working load with allowable tensile stress in beam bottom and slab flange as 12 Mpa. 6 mm diameter bars were used to form the frame to tie the weld meshes. The cast element has dimensional accuracy and uniform strength in the total section. This quality assurance allows the stresses ascertained in the experiments to be used in the design. The dead weight of the cast elements was a maximum of 150 kg for the column 3 m height. All other elements were much less in weight. The erection was done with a hydra (Fig. 6). The erection took only 4 hours.

Fig. No 5 : Column/Slab/Beam Cast Section.

Fig. No. 6 : Erection Sequence Col. Beam & Slab

Encouraged by this experience, it was decided to make a room with load bearing walls of ferrocast elements. A single toilet design was selected. The stiffened walls and slab elements were of 15 mm thickness with two layers of weld meshes. The elements were designed so that the dead weight of any element was less than 120 kg. This facilitates shifting and erection by 4 persons. The connections are with bolts. The casting is done in steel moulds and erection done at site (Fig. 7, Fig. 8, Fig. 9)

The cost of one unit as manufactured in the casting yard is Rs. 8000.00.The price paid by the government for a completed toilet is Rs. 12,000.00. With this design it is easily possible, to complete the toilet with transportation to site, erection and profit. This design was approved by the Ministry of Water and Waster Waste in the Centre Government for implementation throughout India.

The advantage of the system is its speed of manufacture and erection without the requirement of major infrastructure. A casting yard can be set up for a cost of Rs. 5-7 lakhs at any location. The cement required for one unit is 2.5 bags , compared to 8 bags, for conventional brick work toilet unit.

The number of household toilets needed in India is 7 crores , of which Maharashtra State needs 63 lakh units, to be installed in 5 years.

Fig. No. 7 : Casting Moulds

Fig. No. 8 Erection

Fig. No. 9 : Completed Toilet

There are two other types of toilet designs which are needed under Swach Bharat Mission. One is a toilet cum bath and the other is the toilet unit for girls and boys schools. Both are designed with same wall panels. The bath cum toilet unit is given with the rural housing. An estimated total of 2 crore rural housing units of about 25 m2 area with a toilet block is proposed. Designs with ferro cast foundation and superstructure units which are, glued and bolted at site are shown in Fig.10 and Fig. 11.

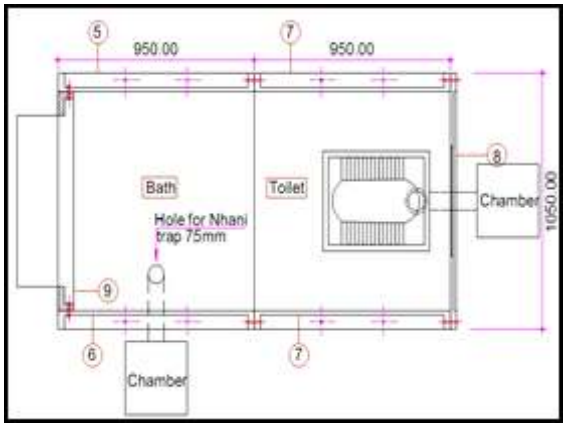

Fig. No. 10 : Toilet Cum Bath

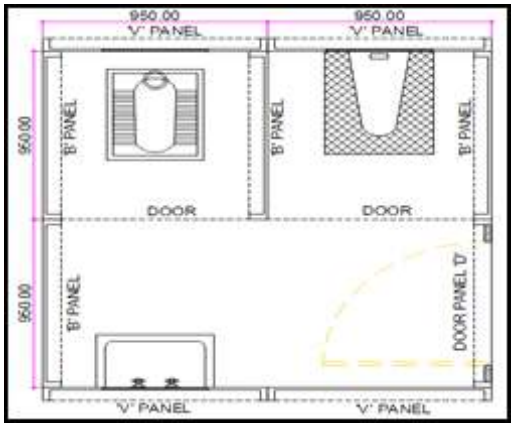

Fig. No. 11 : Girls Toilet for School

The 1 RK units for rural and urban poor are shown in Fig 12 & Fig 13. The cost of construction of the precast houses is about 25-30% cheaper than the conventional system. The time of construction is about 20% of that of conventional system. Both these facts are the main driving forces for selection of precasting system over conventional method of construction. The Urban designs are for G +1 and G +2 as ground floor units will need larger land coverage which may not be available in cities. Fig. 14 shows a design for 1 BHK plan with 12 units per floor. This is a suitable design for Low income group in the cities. The structural support system can be of columns and beams or with load bearing ferrocast insulated walls. As all building elements are cast in moulds, it is very easy to replicate the design if suitable moulds are made available at the casting location.

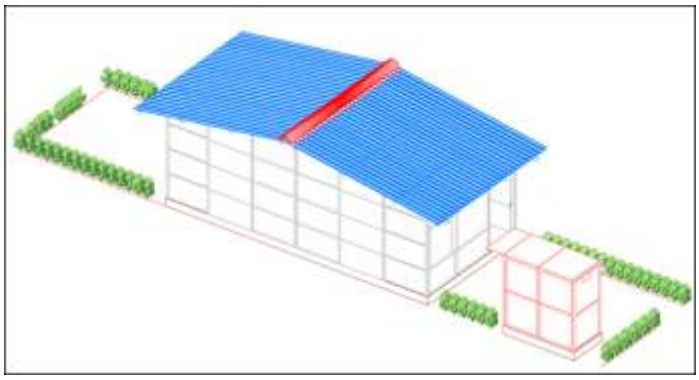

Fig. No. 12 : Rural Housing 27 Sqm with Toilet

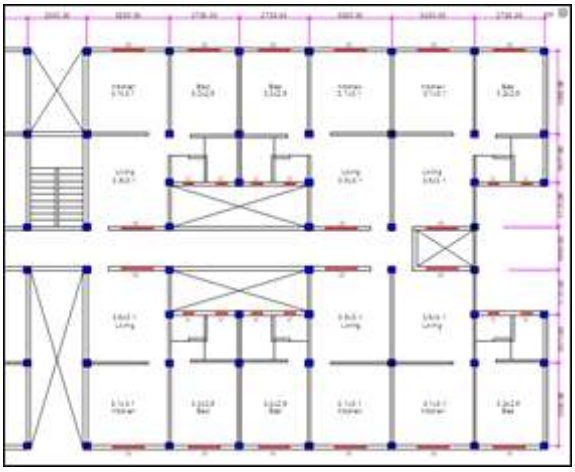

Fig No. 13 : 1 BHK Unit

Fig. No. 14 : 1 RK Unit

The ferrocasting system has several advantages over conventional RCC construction. They are in-numerated below.

a) Factory made elements.
b) High quality and structural performance
c) Light weight, leading to ease of handling in the casting yard, transportation etc.
d) Needs smaller capacity cranes for erection.
e) Reduction in Dead Load leading to structural cost reduction in all members.

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