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Structural Design of Engineering Buildings

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Abstract

The structural design in a limited sense also deals with design of various parts of a structure, and designed to meet the functional aspect takes in to consideration the purpose for which the structure is designed. In structural aspect, it is ensured that the structure is safe strong, durable and economical. The structures are designed for two criteria, viz, the structural safety and economy. Therefore the designed structure must satisfy strength stability and stiffness.

The elastic and plastic method discussed so far is deterministic methods and factor of safety and load factor are selected on subjective judgment rather than any rational basis. So these methods fail to convey correct meaning of safety under all design situations

Limit state design philosophy takes into account the statistical nature of loads and material strengths, thereby providing consistent levels of safety. It's also considers the other requirements such as serviceability and durability.

The conventional methods to introduce safety margin are:

a) IS Elastic Method, b). IS Plastic Method.

Keywords: structural design, Pre-Engineered-Buildings, Staad Pro, Utilization Ratio, Tapered Sections

1. INTRODUCTION

The structural performance of these buildings is well understood and, for the most part, adequate code provisions are currently in place to ensure satisfactory behavior in high winds [1]. Steel structures also have much better strength-to-weight ratios than RCC and they also can be easily dismantled. Pre Engineered Buildings have bolted connections and hence can also be reused after dismantling. Thus, pre engineered buildings can be shifted and or expanded as per the requirements in future.

In this paper we will discuss the Structural design deals with the selection of proper material, proper size, properties and shape of the member. The selection is such that it is economical and safe. It satisfies the entire stress requirement imposed by the most severe combination of loads to which the structure is required to resist including its self-weight. The structural design in a limited sense also deals with design of various parts of a structure, and designed to meet the functional aspect takes in to consideration the purpose for which the structure is designed. In structural aspect, it is ensured that the structure is safe strong, durable and economical. The structures are designed for two criteria, viz, the structural safety and economy. Therefore the designed structure must satisfy strength stability and stiffness.

All the sections of the structures should have strength at least equal to the structural effect of design loads and forces that occur during the construction and use. All the design loads should be taken in to consideration, which a structure would be required to bear. A structure may be required to withstand and loads of, out of the various loads or combination of various loads. The major loads, which are likely to act on the structure, are dead load, live load, wind load and seismic load. Dead load includes self-weight of the structure and all other super-imposed loads, which are permanently, attached to the structure. Live load comprises of those loads whose position or magnitude or both may vary. The wind load is one of the most important loads an engineer has to deal with, which depends on wind velocity and shape of the structure. Seismic force generated in the structure is mainly due to the movement of the earth during earthquake. Seismic force is of prime importance now a day.

Factor of safety is defined as the factor by which the yield stress of the 2.material is divided to give working stress. A greater value of factor of safety used to be adopted formerly and as such the working stresses computed were small. As a result of this a large cross-section of the member had to be adopted in design. From experience gained and experiments made in laboratories, it has been seen that such a large section of a structural member is not required. Hence factor of safety adopted now days is comparatively small. This has resulted in appreciable saving in the material.

While designing a structure, the Civil Engineer has to ensure that structure serves its intended purpose for its lifetime. But he has to take decisions in presence of uncertainty, which is invariably present in practices. Since the physical properties of the materials use for the structure and loads to which it is subjected are random in nature, performance of Civil Engineering Structures is also non-deterministic.

A Civil Engineering Designer has to ensure that the structures and facilities he designs are (i) fit for their purpose (ii) safe and (iii) economical and durable. Thus safety is one of the paramount responsibilities of the designer. However, it is difficult to assess at the design stage how safe a proposed design will actually be. There is, in fact, a great deal of uncertainty about the many factors, which influence both safety and economy. The uncertainties affecting the safety of a structure are due to

i. Uncertainty about loading

ii. Uncertainty about material strength and

iii. Uncertainty about structural dimensions and behavior.

These uncertainties together make it impossible for a designer to guarantee that a structure will be absolutely safe. All that the designer can ensure is that the risk of failure is extremely small, despite the uncertainties. In order to safeguard against these uncertainties, strength of structure must be higher than what is required by analysis. This extra strength is called as safety margin. 3 The conventional methods to introduce safety margin are:

a) IS Elastic Method, b) IS Plastic Method.

1.1 ELASTIC METHOD

The development of linear elastic theories in the 19th century enabled indeterminate structures to be analyzed and the distribution of bending and shear Stresses to be computed correctly. In the Working Stress Method (WSM) of design, the first attainment of yield stress of steel was generally taken to be the onset of failure as it represents the point from which the actual behavior will deviate from the analysis results. Also, it was ensured that non-linearity and buckling effects were not present. It was ensured that the stresses caused by the working loads are less than an allowable stress obtained by dividing the yield stress by a factor of safety. The factor of safety represented a margin for uncertainties in strength and load.

In this method, design of a structural element is done so that stresses computed under the action of working or service loads, do not exceed anywhere in the structure and it is checked at few critical location for some pre designed allowable values. These allowable stresses have attainment of some limiting stress. Most often the upper limiting stress is the minimum specified loads are well within the elastic range. The safety is defined in terms of factor of safety, which is given by In this method, the elastic behavior of the material is considered i.e. Hook‟s law is valid and load-deflection curve is linear. It may be said that, the safety define in the elastic method does not reflect the true safety or the actual safety that is available. The structure design by elastic method is safe under working load and expected to carry the ultimate load. Achievement of yield condition as is the primary objective in the. elastic method. This method is simple and familiar in our country.

In general, each member in a structure is checked for a number of different combinations of loads. Some loads vary with time and this should be taken care of. It is unnecessarily severe to consider the effects of all loads acting simultaneously with their full design value, while maintaining the same factor of safety. Using the same factor of safety when loads act in combination would result in uneconomic designs. A typical example of a set of load combinations is given below, which accounts for the fact that the dead load, live load and wind load are all unlikely to act on the structure simultaneously at their maximum values,

- (Stress due to dead load + live load) = allowable stress
- (Stress due to dead load + wind load) = allowable stress
- (Stress due to dead load + live load + wind) =1.33 times allowable stress.

1.2 PLASTIC MOTHOD

In Plastic design, the service loads are first increased by some factor (load factor) to obtain the desired maximum strength and the structure is then designed to have that maximum strength. Because steel is a ductile material, achievements of a yield condition at one location in a continuous structure does not limit the capacity, but the stresses due to an additional load are distributed differently though the structure. Once a structure has no further ability to carry an increased load, it is said to have reached a "Collapse Mechanism". The ductility of steel which permits yielding to occur without a decrease in strength is defined as plastic behavior; hence the term plastic design is used when the resulting plastic strength is consciously considered in the design process.
The structure designed by plastic method is safe under collapse load and expected to carry ultimate load. Attainment of large strain after reaching a yield condition as is the main objective in plastic design. The method of plastic analysis.
Design is recently developed. This method was thought of around 1935. This method has its main application in the analysis and designs of statically indeterminate frame structure. This method provides striking economy as regards to the weight of steel. The deflection under working loads should not exceed the limit prescribed by Indian standard.

2. REVIEW OF LITERATURE

The main elements of industrial steel structure are beam, column, beam -column, tie and lattice member. Beams are those elements which are subjected to bending moments and shear force only. In some special cases beams are subjected to torsional moments. Columns are subjected to axial load (tensile or compressive). The member can safely be designed as axial loaded column, only very short column can be loaded up to the yield stress. As a result of instability a long column buckle even before developing a full strength of the member. Thus a sound knowledge of compressive member stability is necessary for those designing in structural steel. When significant bending is present in addition to an axial load in a member the member is termed as a Beam-Column. Following theories were developed in order to develop the design philosophy.

2.1 LITERATURE REVIEW
a. COLUMN THEORY

Column buckling theory was first proposed by **Leonhard Euler** who arrived at expression for the critical load for a column for both ends pinned. Euler‟s approach was generally ignored for design purpose because test result does not tally with it. Column of ordinary length used in design is not strong.
Consider and **Engesser** in 1989 independently realized that portion of usual length column becomes inelastic prior to the bucking. They recognized that ordinary length column mostly fail by inelastic buckling, rather than elastic buckling. They realized that only a value, which could account for some of the proportional limit, should be used for Young's modulus in the Euler's expression [1].

b. BASIC COLUMN STRENGTH

Considering a single curvature deflection for the fundamental buckling mode, Euler's arrived at the critical for a column with both ends is pinned as:

$$Pcr = \frac{\pi^2 EI}{(L\,eq)^2}$$

Consider and Engesser found, the above equation is hold good for long column and hence they suggest the above equation for column of ordinary length assuming following assumption.

1. Same compressive stress-strain properties throughout the section.
2. No initial internal stresses exist.
3. The column is perfect straight and prismatic.
4. The load must be act though the centroidal axis of the member until the member begins to bends.
5. The end condition must be determinate so that the definite equivalent pinned length may be established.

Ranking–Gorden Formula

This formula is one of the oldest empirical formula. First suggested by **Tredgold**, it was adopted by **Gorden**. The final of the formula was given by Ranking and hence it is known as Ranking's Formula.

Then, $\frac{1}{\sigma} + \frac{1}{\sigma_c} + \frac{1}{\sigma_b}$ gives the curve that becomes tangential at a $\frac{L}{r} = 0$ and at b $\frac{L}{r} \rightarrow \infty$. This satisfies both the limiting condition. At intermediate values, the curve is below the Euler curve for column of medium height and for long approaches the Euler curve as shown in Fig 2.1

Therefore $\sigma = \frac{\sigma_c \sigma_b}{(\sigma_c + \sigma_b)} = \frac{a}{\left(1 + b\left(\frac{L}{r}\right)^2\right)}$

Where a = σ y

$b = \frac{\sigma_y}{\pi^2 E}$

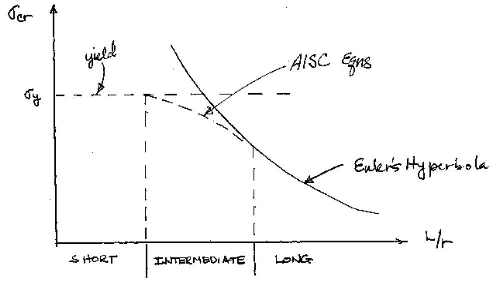

Fig:2.1

American institute of steel construction (AISC) has adopted this formula with b = 1/ 8000 and a =1260 kg /cm^2 for structural steel. According to its 1949 specification, it can be use for the design of secondary members with $\frac{L}{r}$ ratio between 120 and 200. Building code of New York City (1945) had adopted it for secondary members with $\frac{L}{r}$ ratios between 60 and 200 and main members with $\frac{L}{r}$ ratio between 60 and 120.

3. PROPOSED METHOD

This Design Calculations Package has been prepared using the latest applicable Indian codes and standards and the latest developments in engineering practices. Computer programs (STAAD-PRO) have been used where applicable to determine structural requirements.

Applicable Standard Codes

The Industrial gable Building described in these calculations is designed according to the latest Buildings and Design Codes that have been referred to in the design.

The loads as described in the Design Summary Sheet have been applied on the structure in accordance with
a) **IS 875-1987** (Part –1,2 and 3), Code Of Practice For Design Loads (Other Than Earthquake For Building & Structures)
b) **IS-1893-2002** (Part –1) Indian standard criteria for earth quake resistant design of structures (Part-1 General Provisions and buildings).

a. Material Specifications

The following is the list of the material standards and specifications for which the building components have been designed.

Element	**Comparison Table of WSM vs LSM**			
	WSM		**LSM**	
	Web	Flange	**Web**	Flange
Rigid Frame Column (mm)	650 x 8	200 x 10	600 x 8	200 x 12
End wall Column (mm)	650 x 8	150 x 8	600 x 8	175 x 8
Rafter (mm)	650 x 8	200 x 10	600 x 8	200 x 12
Sidewall Girt (mm)	ISLC-150		ISLC-175	
End wall Girt (mm)	ISLC-250		ISLC-300	
Purlin (mm)	ISLC-150		ISLC-175	
Bracing (mm)	L-130 x 130 x 8		L-130 x 130 x 8	

b. Comparison Table of WSM VS LSM

Element	**Comparison Table of WSM VS LSM**	
	WSM	**LSM**
Rigid Frame Column Base Plate (mm)	30	36
Endwall Column Base Plate (mm)	30	40
Knee Splice Plate (mm)	32	30
Ridge Splice Plate (mm)	30	25
Element	**Comparison Table of WSM VS LSM**	
	WSM	**LSM**
Rigid Frame Column Anchor Bolt (mm) Dia.	30 (4.6 Grade)	36 (4.6 Grade)
Endwall Column Anchor Bolt (mm) Dia.	36 (4.6 Grade)	36 (4.6 Grade)
Knee Splice Bolt (mm) Dia.	24 (8.8 Grade)	24 (8.8 Grade)
Ridge Splice Bolt (mm) Dia.	20 (8.8 Grade)	20 (8.8 Grade)

4. EXPERIMENT AND RESULT

The design of typical gable frame of industrial building is carried out using Elastic Method and Limit State Methods as suggested by Indian Standard code .Analysis of the building is carried out using Staad-Pro results of analysis i.e. governing forces are tabulated in respective member design. Design results of both the method are tabulated.

5. CONCLUSION

After carrying out detailed analysis & design of an Industrial steel structure using both working stress method (IS800-1984) & Limit state method (IS800-2007) it is observed that there is increase in structural weight from

WSM to LSM (this may differ from case to case) Following points are considered for comparison of two methods,

1. **Safety Factors** – In LSM (IS800-2007) Separate Partial Safety Factors for different loads and combinations are considered based on the probability of occurrence of the loads. Similarly different safety factors for materials are also considered depending on perfection in material characteristics and fabrication /erection tolerances. Whereas in WSM (IS800-1984) unique factor of safety was considered irrespective of probability of load occurrence & perfection in material.

2. **Additional factors for design** – few additional factors are incorporated for element/member design in LSM (IS800-2007) which were not included in WSM (IS800-1984)

a) **Section Classification:** The new edition of IS: 800-2007 clearly classify cross sections as to, Plastic, Compact, Semi-Compact or Slender. Separate design procedures have been laid down for each type of Classification. The classification has been made based on each element of the section involved and depends on the ratio of the major and minor dimension of the element i.e., limiting width to thickness ratio.

b) **Tension Members:** Tension members have been designed by considering not only failure of the net cross section (after taking Shear Lag) but also considering yielding of the gross cross section and rupture of the section at the joint.

c) **Compression Members:** Design of Compression members considers the appropriate buckling curve out of total four numbers depending on the type of section and the axis of buckling. Earlier version of the Working Stress Method of design considered only one buckling curve for all types of members irrespective of the nature of buckling.

d) **Members Subjected to Bending:** Reduction in Flexure capacity due to high Shear Force has been elaborated in detail. LSM introduces tension field design of plated steel girders which was not considered in WSM (earlier version).

e) **Members Subjected to Combined Forces:** Moment Gradient across a member / element considered in detail, while designing against combined action of axial force and bending moment in an element of a structure.

f) **Design against Fatigue:** Design against fatigue has been introduced for the first time. The state-of-the-art concept of stress range has been introduced for the first time in this code, This code automatically supersedes IS:1024 for steel structures which considered the stress – ratio method..

g) **Earthquake Resistance:** Response Reduction factor has been introduced and elaborated in the new edition for the first time.

Limit state design is a design method in which the performance of a structure is checked against various limiting conditions at appropriate load levels. The limiting conditions to be checked in structural steel design are ultimate limit state and serviceability limit state. Limit state theory includes principles from the elastic and plastic theories and incorporates other relevant factors to give as realistic a basis for design as possible. Special features of limit state design method are,

- It is possible to take into account a number of limit states depending upon the particular instance
- This method is more general in comparison to the working stress method. In this method, different safety factors can be applied to different limit states, which is more rational than applying one common factor (load factor) as in the plastic design method
- This concept of design is appropriate for the design of structures since any new knowledge of the structural behavior, loading and materials can be readily incorporated.

 The limit state design method is essentially based on the concept of probability. Its basic feature is to consider the possibility and probability of the collapse load. In this respect, it is necessary to consider the possibility of reduced strength and increased load.

 Serviceability and the ultimate limit state design of steel structural systems and their components.

 Due importance has been provided to all probable and possible design conditions that could cause failure or make the structure unfit for its intended use.

 The basis for design is entirely dependent on actual behavior of materials in structures and the performance of real structures, established by tests and long-term observations.

 The main intention is to adopt probability theory and related statistical methods in the design.

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