Plastic Analysis of Steel Structure

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Abstract— Plastic analysis offers several advantages over the traditional elastic analysis. With plastic analysis, a structure can be designed to form a preselected yield mechanism at ultimate load level leading to a known and predetermined response during ultimate condition. In plastic analysis of a structure, the ultimate load of the structure as a whole is regarded as the analysis criterion. The term plastic has occurred due to the fact that the ultimate load is found from the strength of steel in the plastic range. Varition of stress distribution in Elastic, Elasto-Plastic, and Plastic section. It include advantages and disadvantages of Plastic method. Paper also explain about plastic hinge, plastic moment, shape factor, methods of plastic analysis. Necessary conditions for plastic analysis and elastic analysis. Redistribution of bending moment at plastic state.

Key words: Plastic analysis, Ultimate load, Stress distribution, Mechanism, Plastic hinge, Plastic moment, Shape factor, Upper bound theorem, Lower bound theorem, Collapse

I. Introduction

A. Plastic analysis:

Basically there are two methods to provide adequate strength of structures to support a given set of design loads. Elastic analysis and Plastic analysis

It is commonly understood that most structures analyzed by elastic method possess considerable reserve strength beyond elastic limit until they reach their ultimate strength or plastic state. The reserve strength is derived from factors, such as structural redundancy, ability of structural members to deform in elastically without major loss of strength (i.e., ductility), etc.

In plastic analysis of a structure, the ultimate load of the structure as a whole is regarded as the design criterion. The term plastic has occurred due to the fact that the ultimate load is found from the strength of steel in the plastic range. This method is rapid and provides a rational approach for the analysis of the structure. The steel sections required by this method are smaller in size than those required by the method of elastic analysis. Plastic analysis and design has its main application in the analysis and design of statically indeterminate framed structures.

Plastic analysis is economical, less laborious, less time consuming. Deflections at working load level of fixed beam designed by plastic method is always less than that of corresponding simply supported beam designed by working stress method.

Margin of safety in plastic method same as that of elastic analysis. Reserve in strength is considerable.

B. Assumptions made in plastic analysis:

1) Plane section remains plane implying that the strain distribution is linear.
2) The idealized stress- strain curve for steel is,

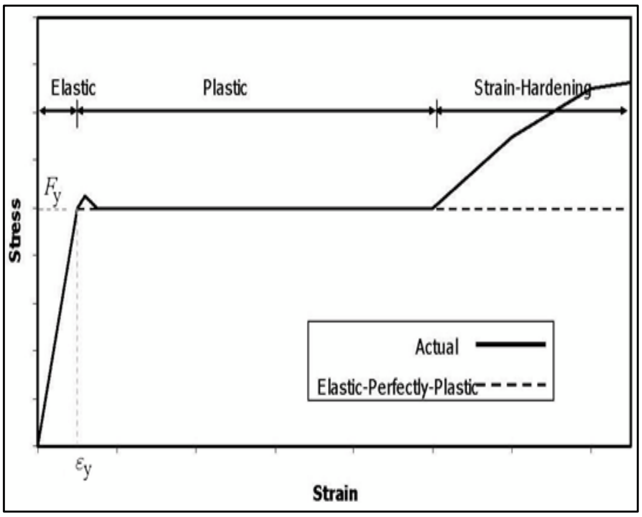

Fig. 1: Typical Stress-Strain Diagram of Structural Steel.

3) Deformations are small.
4) Stress-Strain curve is same in Tension and Compression.

II. Literature survey

The number papers published on Plastic analysis, the paper “Plastic versus Elastic Design of steel structures” which was published in 2011 he presents an overview of plastic design concepts and their modern applications in designing the structure with a preselected yield mechanism for enhanced performance under extreme loading. A design example is then presented to illustrate the contrasts between elastic and mechanism-based plastic design approaches.

Another paper in 2012 by M. Rogac and a group published “Plastic analysis of Steel Frame structure” This paper presents the plastic analysis of steel frame structure loaded by gravity loads. By applying the cinematic theorem of ultimate analysis, the ultimate load for the case of elastic - ideally plastic material is calculated.

Another paper by S R Satish Kumar and group present the “Basic Plastic Analysis” it gives the behavior of structure under ultimate load. Another paper by Van-Long Hoang and a group published “An Overview of the Plastic hinge analysis of 3D Steel Frames”.

Another paper in 1990 by Ram Chandra and group on “Elastic-Plastic Analysis of Steel Space Structure” a new concept of instantaneous secant stiffness is proposed and used for nonlinear elastic-plastic analysis of steel space structure.

Another paper in 2002 by K H Tan and group publish a paper on “Visco-Elasto-Plastic Analysis of Steel Frames in Fire”

III. STRESS DISTRIBUTION

A. Elastic Section:

The stress at any fibre in the section is less then yield stress. Extreme fibre stress less then yield stress. The stress distribution in the Elastic section is linear

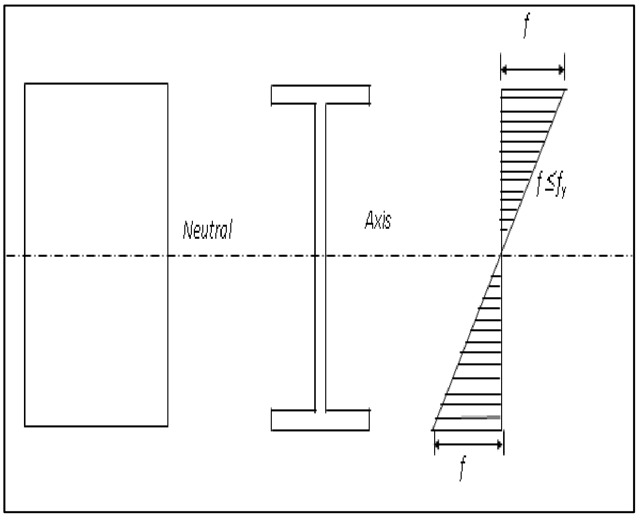

Fig. 2: Elastic Stresses in Beams

B. Elastic-Plastic Section:

The beam is subjected to a moment slightly greater than Elastic moment, it produces the yield in the extreme fibres, and it does not fail. Fibres near the neutral axis does not yield still in Elastic stage. That is partially yielded.

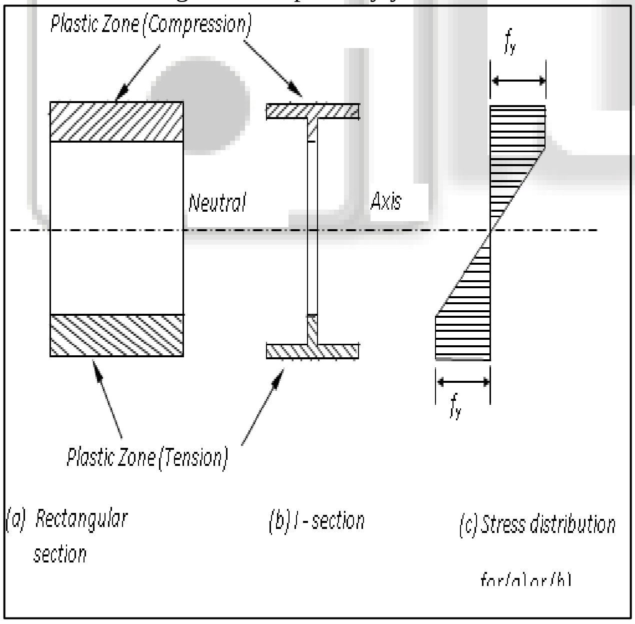

Fig. 3: Stresses in Partially Plastic Beams

C. Plastic Section:

As the moment is increased up to Plastic stage, the plastic zones increase in depth and reaches the neutral axis and it divides the section in to two stress blocks.in this section the fibre near the neutral axis fully yielded. In plastic section the stress distribution is uniform.

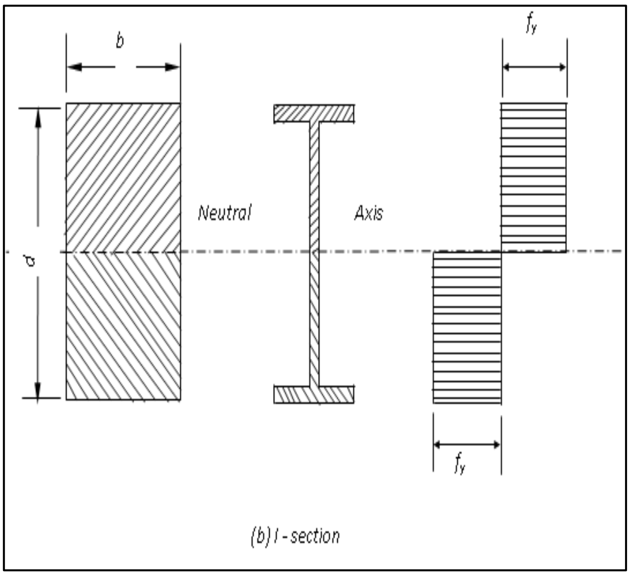

Fig. 4: Stresses in Fully Plastic Beams

IV. SHAPE FACTOR

The ratio of the plastic moment to the yield moment is known as the shape factor since it depends on the shape of the cross section. The cross section is not capable of resisting any additional moment but may maintain this moment for some amount of rotation in which case it acts like a plastic hinge. If this is so, then for further loading, the beam, acts as if it is simply supported with two additional moments Mp on either side, and continues to carry additional loads until a third plastic hinge forms at mid-span when the bending moment at that section reaches Mp. The beam is then said to have developed a collapse mechanism.

The zone of yielding in a flexural member is known as Plastic hinge. The bending moment at the section where a plastic hinge form is known as Plastic moment is always greater than the yield moment.

Plastic hinge rotates indefinitely at a constant moment value of plastic moment Mp. The plastic hinge is identified as a point and assumed to occur at a particular point in a cross section.

Plastic hinge is spread over a zone in a structural member called the length of plastic hinge.

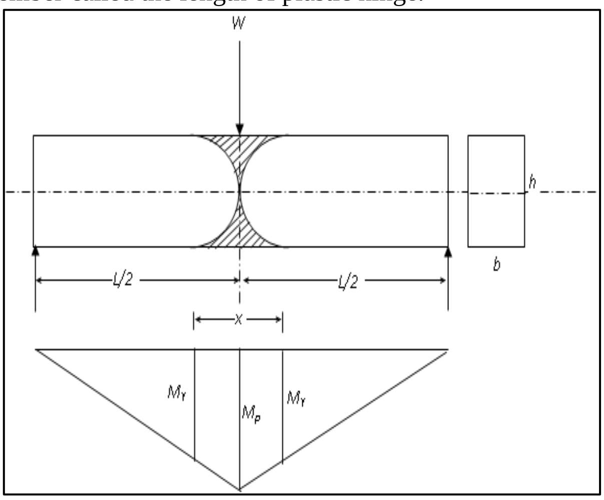

Fig. 5: Hinged Length of a Simply Supported Beam with Central Concentrated Load

Length of plastic hinge depends upon the type and shape of cross section, end condition of the member and the type of loading.

In Plastic analysis the redistribution of bending moment takes place. That is the distribution of bending moment from high yield stress to low yield stress till the stress distribution in the section is uniform.

Shape factor is a measure of reserve in strength beyond elastic limit in a cross section. The shape factor indicate the plastic section withstand the load how higher then the elastic section.

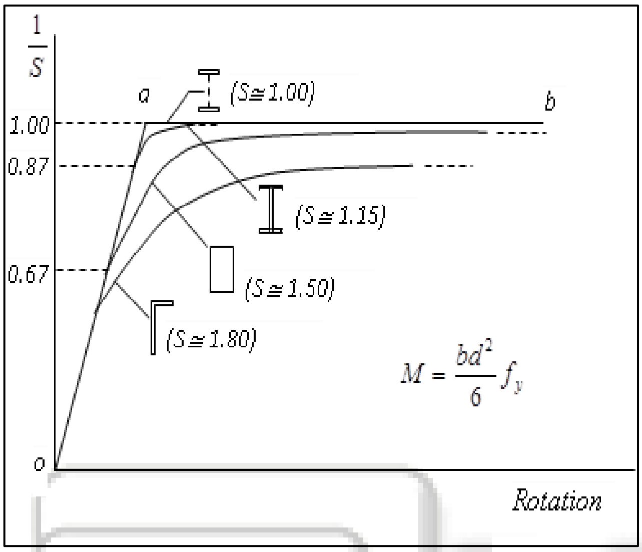

Fig. 6: Moment – Rotation Curves

V. FUNDAMENTAL CONDITIONS FOR PLASTIC ANALYSIS

A. *Mechanism condition:*

The ultimate or collapse load is reached when a mechanism is formed. The number of plastic hinges developed should be just sufficient to form a mechanism.

B. *Equilibrium condition:*

$\sum Fx = 0, \sum Fy = 0, \sum Mxy = 0$

C. *Plastic moment condition:*

The bending moment at any section of the structure should not be more than the fully plastic moment of the section.

VI. THEOREMS OF PLASTIC ANALYSIS

A. *Lower Bound or Static Theorem:*

A load factor (λs) computed on the basis of an arbitrarily assumed bending moment diagram which is in equilibrium with the applied loads and where the fully plastic moment of resistance is nowhere exceeded will always be less than or at best equal to the load factor at rigid plastic collapse, (λp). In other words, λp is the highest value of λs which can be found.

B. *Upper bound or Kinematic theorem:*

A load factor (λk) computed on the basis of an arbitrarily assumed mechanism will always be greater than, or at best equal to the load factor at rigid plastic collapse (λp). In other words, λp is the lowest value of λk which can be found.

C. *The Uniqueness Theorem:*

If for a given frame and loading at least one safe (strength greater than moment demand condition) and statically admissible bending moment distribution (equilibrium condition) can be found, and in this distribution the bending moment is equal to the fully plastic moment at enough cross-sections to cause failure of the frame as a mechanism due to rotations of plastic hinges at these sections (mechanism condition), the corresponding load will be equal to the collapse (ultimate) load.

VII. MECHANISM

When a system of loads is applied to an elastic body, it will deform and will show a resistance against deformation. Such a body is known as a structure. On the other hand if no resistance is set up against deformation in the body, then it is known as a mechanism.

A. *Independent Mechanism:*

Independent mechanism takes place due to particular structural action and restricted to particular members only or particular joints only.

1) *Beam Mechanism:*

In beam mechanism the plastic hinge occurs at supports as well as span section.

When load applied with in the span of the member the beam mechanism occur.

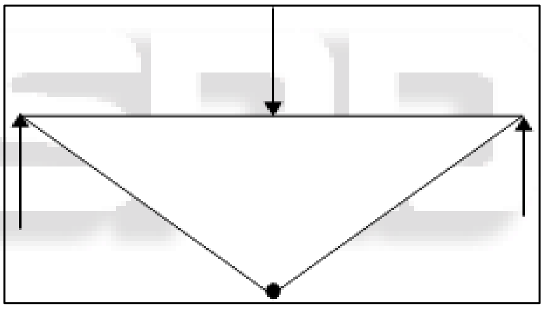

Fig. 7: Beam Mechanism

2) *Panel or Sway Mechanism:*

In panel or sway mechanism there is no hinge with in the span.

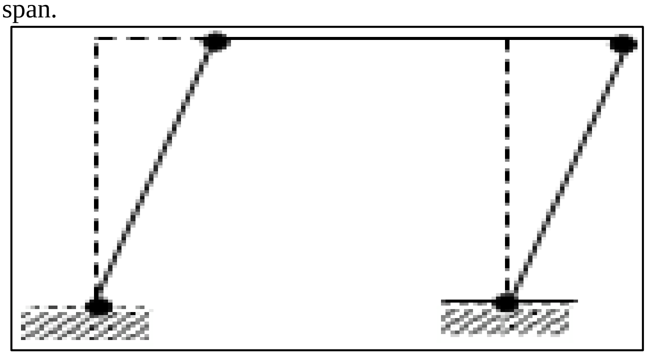

Fig. 8: Panel or Sway Mechanism

3) *Gable Mechanism:*

The special mechanism, provoked in gable. In this the plastic hinge occur within the gable.

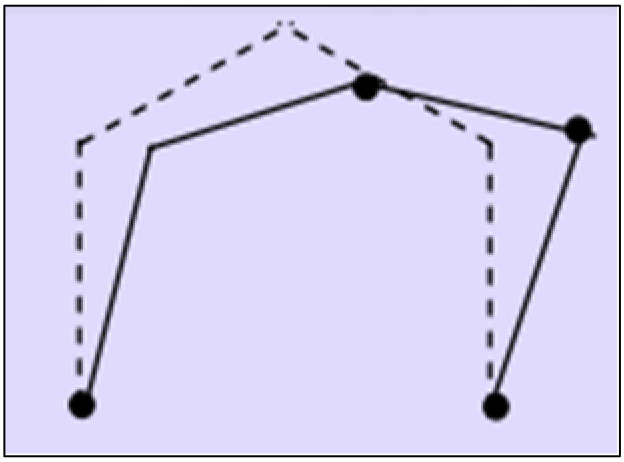

Fig. 9: Gable Mechanism

4) Joint Mechanism:

It occurs at a joint where more than two structural members meet.

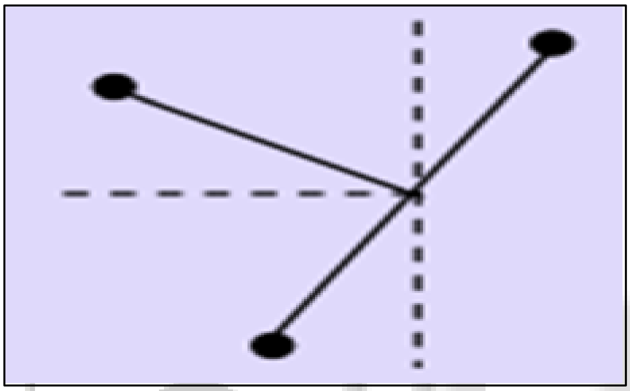

Fig. 10: Joint Mechanism

B. Combined Mechanism:

The combined mechanism obtained due to combinations of two or more independent mechanism.

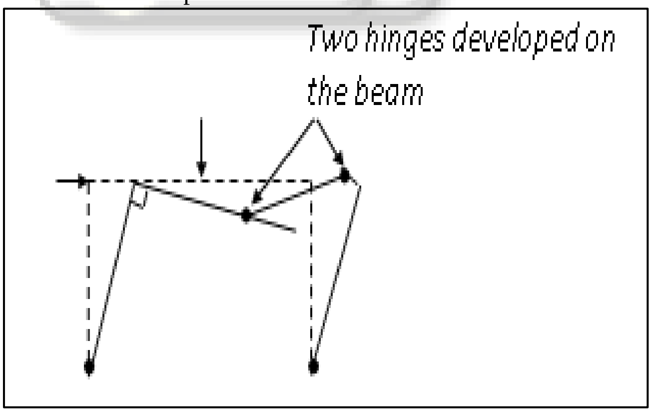

Fig. 11: Combined Mechanism

VIII. Conclusion

Basic concepts on Plastic Analysis have been discussed in this paper and the methods of computation of ultimate load causing plastic moment have been outlined. Theorems of plastic analysis and alternative patterns of hinge formation have been discussed. The stress distribution in different stages of the section have been discussed in this paper. The shape factor for different sections and the formation of plastic hinge implemented above. The fundamental conditions for plastic analysis and theorems of plastic analysis are mentioned. The mechanisms of plastic analysis also discussed too.

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