International Journal of Advanced Technology in Engineering and Science
Vol. No.4, Issue No. 01, January 2016
www.ijates.com
ijates
ISSN 2348 - 7550

OPTIMIZATION OF STIFFENED PLATE GIRDERS – AN OVERVIEW

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ABSTRACT

Generally Optimization aims to obtain the best results in a given circumstances or to minimize input to maximize the benefits. They are formulated to improve structural properties under consideration of specified constraints. The Optimization methods are nearly as old as calculus but reached prominence in the digital age. Nowadays numerous optimization techniques have been used in various fields. In this paper a basic overview of various research carried out on optimization of stiffened plate girders are discussed. Along with the optimization techniques, various experimental works on stiffened plate girders has also been discussed. Number of optimization techniques exists and it is not convenient to discuss about all those techniques. Considering that, an effort is made to concentrate on techniques that are commonly adopted for the past two decades.

Keywords: Genetic Algorithm, Optimization, Plate Girders, Objective Function, Mutation, Crossover.

I. INTRODUCTION

Generally I-beams made up from separate structural steel plates which are welded together to form the vertical web and horizontal flanges of the beam. It became popular during early1800's railroad bridges and it was done using angles and rivets. By 1950's welded plate girders replaced riveted and bolted plate girders. Whenever the webs are inadequate to carry load, they are made strong and stable by a provision of wide variety of stiffeners. Figure 1 shows the longitudinal elevation of a plate girder with transverse stiffeners.

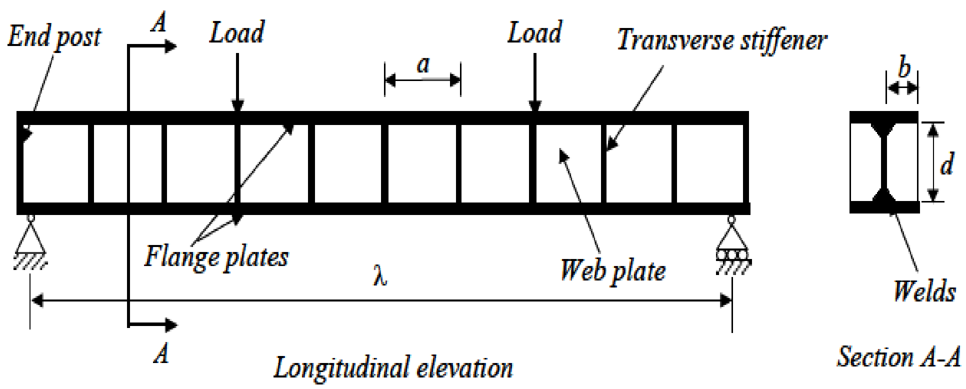

Figure 1: Elements of a plate girder

1.1 Advantages of a Stiffened Plate Girder

- Cost of fabrication is low compared to trusses
- It requires minimum amount of vertical clearance
- Due to compactness, vibration & impact are not serious problem
- The designer has greater flexibility in choosing the dimension which is the reason for optimization.

1.2 Optimization of Plate Girders

Optimization techniques play an important role in structural design, the very purpose of which is to find the best solutions from which a designer or a decision maker can derive a maximum benefit from the available resources.The objective functions are obtained by calculating each event and multiply it by the corresponding probability. The sum of all such products will be the total objective function. The constraints may also be probabilistic. These are suitable in situations when the loads acting on the structure are probabilistic or the material properties are random. The optimization problem is classified on the basis of nature of equations with respect to design variables. If the objective function and the constraints involving the design variable are linear then the optimization is termed as linear optimization problem. If even one of them is nonlinear it is classified as the non-linear optimization problem. In general the design variables are real but sometimes they could be integers for example, number of layers, orientation angle, etc. The behaviour constraints could be equality constraints or inequality constraints depending on the nature of the problem.

The primary functions of the web plate in a plate girder are to maintain the relative distance between the top and bottom flanges and to resist the introduced shearing force. In most practical ranges of span lengths for which a plate girder is designed, the induced shearing force is relatively low as compared with the axial forces in the flanges resulting from flexure. As a result, the thickness of the web plate is generally much smaller than that of the flanges. Consequently, the web panel buckles at a relatively low value of the applied shear loading. The webs are often reinforced with transverse stiffeners to increase their buckling strength, and web design involves finding a combination of an optimum plate thickness and stiffener spacing that renders economy in terms of the material and fabrication cost.

Traditional optimization techniques have been applied diligently in structural engineering during the past three decades. However, the major obstacle in using them is their mathematical complexity and only certain types of structural problems can satisfy their rigid requirements. Consequently, research was oriented in the direction of improving the traditional techniques and/or perhaps finding better approaches of dealing with the problems in structural optimization. Soft computing techniques such as the GA were found to behave efficiently over a wide range of applications, even when employing numerous design variables and constraints.

II. NEED FOR OPTIMIZATION

Initially, the development of optimization began during the period of World War II to optimize the trajectory of missiles. Subsequently, mathematical programming has been developed to realize optimization through mathematical techniques. In the past, new optimization techniques had been developed in each era to realize customer solutions. But now those optimization techniques are dated and new solutions are being realized.

It is needed the most where the best possible design alternatives of specific structures are necessary. The best possible or optimal structure is the structure which is essential for engineers. It can be reliable and efficient if correctly applied. The most advanced techniques of optimization are already into industrial practices.

III. LITERATURE REVIEW

The literature collected is grouped into the following areas.

1. Optimization of Plate Girders with Transverse Stiffeners
2. Experimental work on Plate Girders with Transverse Stiffeners.

The overview of the literature studied is briefly discussed below.

3.1 Optimization of Plate Girders with Transverse Stiffeners

1. **Koji Homma (1994)** in his paper titled **"Potential for high performance steel in plate girder bridge designs under the LRFD code"** focuses on the potential for high performance steel in plate girder bridges designed for the new LRFD bridge design code. To compare designs using high performance steel with designs using conventional steel, optimum designs are developed. To establish optimum designs, a computer program based on LRFD code was developed and used. The computer program is divided into two parts: (i) code conformance analysis (ii) optimization analysis. It is done for two existing bridges: A simple and a continuous composite I section plate Girder Bridge. They were redesigned using high performance steel. The studies show the weight reduction with increasing the yield strength can be obtained up to a yield strength of 70 ksi. The major limitation of this study is that deflection limits were not considered in the analysis. The conclusions of this study are as follows:

- Program based on new LRFD bridge design code were developed
- The weigh of composite steel plate I section girder cross sections can be reduced by increasing the steel yield strength up to a yield strength of 70 ksi.
- Due to limit on the use of design criteria for compact sections, the use of steel with yield strength of 85 ksi or more appears to be ineffective.
- Weight reduction cannot always be obtained using steels in strength of 100 ksi with current plate girder design.
- The development of fatigue resistant details is necessary to take advantage of steel with 100 ksi yield strength or more.

2. **M. Asghar Bhatti, A.S.Al-Gahtani (1995)** in their paper titled **"Optimum design of welded plate girders subjected to highway bridge loading"** have presented a Optimum design of welded Plate Girders subjected to highway bridge loading. The proposed formulation is capable of handling composite or non composite designs, shored or unshored construction, stiffened or unstiffened designs, symmetric or unsymmetrical cross section, simple or continuous spans and prismatic or non prismatic girders. The given problem is constrained to satisfy the AASHTO specifications. For the Optimization Formulation, the design variables are defines as Top flange area, Bottom flange area, Web depth, Web thickness, Stiffener spacing. The objective Function is minimized subjected to bending stress, shear stress, slenderness ratio, and deflection and depth limitations. The paper claims that the optimization

process took about 9 to 12 iterations. Thus the optimization from the proposed formulation concludes that:

- The economical design can be obtained by the designer for different designs in relatively short time even at the preliminary stage.
- The efficiency of the proposed formulation subjected to AASHTO loads are very encouraging.
- Similar formulations can be applied to determine the economical design for other type of bridges especially for long span and where the dead loads are dominant in the optimum design.

3. **F. Shahabian, H. Rajabi mashhadi, J. Farzaneh** in their paper titled **"Optimum design of Plate Girders using Genetic Algorithm"** have carried out optimum design of Plate Girders using the optimization tool, Genetic Algorithm. The main focus of the paper is to minimize the weight of the girders subjected to the constraints established by the design codes. They have studied the girders with various span lengths and loadings. Results that were obtained from Genetic Algorithm were compared with the results obtained from the traditional techniques. It was found that GA was more accurate. Along with that a parametric study was made using GA to investigate the influence of web slenderness and flange rigidity on the optimum design of Plate Girders. Plate girder with transverse stiffeners was adopted here. They have used 9 independent design variables namely, spacing between the stiffeners and end support, spacing between the stiffener and middle support, web slenderness ratio, depth of the web, stiffener thickness, breadth of stiffener, width of the flange, thickness of the flange. The investigation was done on a wide range of web slenderness ratio from 260 to 340 in 10 increments and flange rigidity ratio from 10 to 32 in 1 increments. Based on the parametric study, the following inferences were made:

- The Flange rigidity ratio over 14, when the web slenderness ratio increases, the weigh saving increases.
- The Proposed GA based technique was capable of finding light Plate Girder design when compared with the other Traditional techniques.

4. **Saeid A. Alghamdi (2002)** in his paper titled **"Design optimization of non-uniform stiffened steel plate girders – a computer code"** has presented an optimized design of non-uniform stiffened steel plate girders using a FORTRAN computer code. He has focused on minimum weight of plate girders in this paper. The design specifications are based on the American Institute of Steel Construction. Several example design cases have also been run to compare the efficiency of the design code using the direct search method of reduced gradient and to compare the design results obtained from the ASD and LRFD design specifications. The design variables such as Span ratio, Moment co-efficient, Web plate thickness, flange plate thickness, Steel yield strength. The parametric studies were carried out on moment coefficient, web depth, plate thickness, ratio of areas, steel strength, support conditions and web stiffeners in order to study the sensitivity of design results to key design variables and to provide some general recommendations for design of non-uniform stiffened steel plate girders. The comparison of the numerical results of design studies conducted in this work indicates that,

- The hoc design code proves to provide less computing costs and more material savings
- The code allows the designer a choice to use either LRFD method or ASD method, but LRFD method does provide more economical designs

- Optimum value of span ratio for medium values of plate thickness is within the range from 1 to 1.4 for both the methods
- Optimum value of moment coefficient is within the range from 0.13 to 0.21 for both the methods
- The results obtained using LRFD procedure is more optimal since it is based on more realistic strength and load factors.

5. **Richard P. Knight (2003)** in his paper titled **"Economical Steel plate Girder briges"** has conducted hundreds of studies of steel plate girder bridges using its Preliminary Bridge Girder Optimization program. He claims that it is unique because it optimizes plate girder designs on the basis of least cost, not least weight. He offered the guidelines based on some study results for continuous composite bridges with span lengths of up to approximately 200 ft. He has compared various parameters on a cost index basis. The variables such as Load factor Vs working stress design, weathering steel, painted high-strength steel, number of girders in a cross section, optimum web depth and thickness, transverse vs longitudinal web stiffeners, flanges and flange splices and other considerations leading to cost effective steel plate girders for bridges. As a result, he concludes that,

- Load factor design is more economical than Working stress design.
- Modifying Load factor design by imposing higher loads than on working stress design nullifies the usual cost advantage of Load factor design.
- Weathering steel bridges are more economical than those requiring painting of the whole structure.
- The most economical painted design is hybrid. Painted 50 ksi (345 MPa) homogenous designs are a close second.

6. **M.M. Alinia (2004)** in the paper titled **"A study into Optimization of stiffeners in plates subjected to shear loading"** studies about the optimization of stiffeners in plates subjected to shear loading. By using ANSYS finite element method of analysis, some 1200 plates are analyzed in order to study the role of stiffeners. This Eigen value method is first validated with the theoretical calculations and known cases for a wide range of panel geometries. Initially a numerical modelling is done in APDL programming language followed by trial runs to carry out the convergence of the results. Then the effect of stiffeners on shear buckling stress is studied. The optimum stiffness ratios of plate stiffeners for different aspects ratios and number of stiffeners were shown. It also shows the optimum percentage of increase in critical shear stress of stiffened plates in comparison to the unstiffened ones, for different values of plate's aspect ratios and number of transverse stiffeners. They are discussed as follows: The dimensions of stiffeners are considered in terms of their flexural rigidity, effect of number of stiffeners is studied and the effect of type or geometry of stiffeners are discussed. The concluding remarks are as follows:

- By increasing the aspect ratio of a plate, the amount of increase in critical shear stress lessens and gradually becomes negligible. The number of panels produced by intermediate stiffeners should not be less that the value of plate's aspect ratio.
- All plates which have a similar aspect ratio and number of transverse stiffeners have an optimal value of the flexural stiffness ratio for which the critical shear stress is at its highest possible value.

7. **Kuan-Chen, Yujia Zhai, Saijun Zhou(2005)** in their paper titled **"Optimum design of welded steel Plate Girder bridges using a Genetic Algorithm with Elitism"** has done their research on Optimum design of welded plate girder bridges using Genetic Algorithm with Elitism. Their main focus is to minimize the weight and cost of the girders. They had adopted a simply supported single span bridge and a two equal span continuous bridge with variable parameters as Distance b/w girders, Depth of girder, Thickness of web, Breadth of top and bottom flange, Thickness of top and bottom flange. The Objective function and Constraints such as Dimensional constraints, Stress constraints and Deflection constraints were adopted. The design Loads were specified based on the AASHTO specifications. They have set two criteria for the convergence of the optimization procedure: (i) The maximum number of generations must not be more than 5000 (ii) The ongoing GA procedure should be concluded when a stable point is reached. Apart from this, a parametric study has also been conducted on span length such that, For a single span bridge the span lengths from 100 to 400 ft in 20 ft increments were adopted and for two span continuous bridge the span length from 200 to 400ft in 20ft increments. Parametric studies on Girder spacing, Depth and thickness of Web plate, Width and thickness of Flange plate is also made. Comparison of optimum Designs in Two types of bridges is done as a final part. From the studies and comparison they have concluded that,

- Longer the span length, bigger the cost savings.
- The continuous beam has more effective utilization of material than a simply supported beam.

8. **R.Abspoel (2009)** in the paper titled **"Optimising Plate Girder design"** has optimized the design of plate girder and says that a high degree of optimisation is possible. It is achieved mostly by making the web of the plate girder more slender. To study the design aspects and to study the failure behaviour a FEM model was built. In this paper the results of the laboratory tests and the results of the FEM models are presented and discussed. The main parametric study was on the Web Slenderness ratio which was compared with the Laboratory test results. Initially restrictions were made based on research of Basler. Since there was no torsional buckling of the top flange due to the smaller distance between the transverse stiffeners, additional laboratory tests were carried out. It is found that from the FEM model, girder collapsed by yielding of flange. On comparison of results from the Laboratory and FEM, the following temporary conclusions were made:

- Flange induced buckling occurs most of the time in the inclining part of the Load Vs Deflection diagram
- Yielding of the flanges is the collapse mode for the un-stiffened Plate Girders
- The maximum load of laboratory test girders were lower than the effective bending moment resistance based on EN 1993-1-5, except one girder.
- The Bending moment resistances of the laboratory test girders determined using the formula given by Veljkovic and Abspoel are smaller than the effective bending moment resistance based on the code EN 1993-1-5.

9. **F. Faluyi and C. Arun (2012)** in their paper titled **"Design optimization of Plate Girder using Generalized Reduced gradient and constrained Artificial Bee colony Algorithms"** have optimized the design of Plate Girder using Generalized Reduced Gradient and Constrained Artificial Bee Colony Algorithms. The Generalized Reduced Gradient algorithm available in Excel Solver and the Constrained

Artificial Bee colony algorithm were utilized to optimize the design of plate girder for minimum weight given the span and grade of the material of the girder. A Constrained optimization problem was adopted by considering various parameters and providing maximum stiffener spacing. The design parameters such as Span and yield strength can be taken as fixed values of design parameters. And parameters like top flange width and thickness, web height and web thickness, bottom flange width and thickness, stiffeners thickness and stiffener spacing can be taken as design variables. Several constraints are added such as Dimensional constraint, Sectional classification, Moment resistance, Shear capacity, Serviceability and stiffener check. From the result obtained using Solver Generalized Reduced Gradient Algorithm and Artificial Bee colony Algorithm, there is much assurance that the function was not trapped in the local minima thus lending credibility to the result. They have also obtained a curve for a given web depth, gives the optimal cross sectional dimensions of the girder and the stiffener. It is observed that the reduction in depth of the girder caused increase in thickness of flange plate. Increase in depth of the girder translates to reduction in cross sectional area of the girder. There was slight increase in web thickness with increase in depth of girder. The width of flange reduces as the thickness of the flange increases. The research concludes that,

- It is demonstrated how parametric optimization of a welded beam section can lead to significant reduction in weight of the beam.
- In particular, the Generalized Reduced Gradient algorithm yielded a 7.44% reduction in girder cross sectional area compared to the initial design
- Artificial Bee Colony algorithm enabled a 7.25% reduction in the area.

10. **Roland Abspoel (2014)** in his paper titled **"The maximum bending moment resistance of Plate Girders"** has carried out optimized bending moment resistance of a plate girder given a certain weight per unit length. He claims that, using higher steel grades, applying most material in the flanges and increasing the lever arm between both flanges are the main possibilities to maximize the bending moment resistance of a plate girder under pure bending of a certain amount of steel. For plate girders with a very slender web the stiffness is not decisive and the strengths of the material can be better exploited, so using higher steel grades can be very useful. After optimizing the Bending moment resistance of plate girders investigated from various elaborate literatures, he concludes that,

- The maximum bending moment resistance for a certain amount of steel depends on the maximum of the product of reduction factor and W and not on the maximum of the reduction factor alone.
- The maximum web slenderness ratio is not determined by vertical buckling of the compressed flange into the web and is much higher than based on the code EN 1993-1-5.
- The model to determine the bending moment resistance according Abspoel gives good results compared with the results of the experiments and the FEM.

3.2 Experimental work on Plate Girders with Transverse Stiffeners

1. **Sung C. Lee and Chai H. Yoo, J (1998)** in their paper titled **"Strength of Plate Girder web panels under pure shear"** studies about the Strength of Plate Girder Web panels under pure shear. Nonlinear analyses have been conducted on three-dimensional finite element models of transversely stiffened plate girder web panels (without longitudinal stiffeners) subjected to pure shear including the effects of initial

out-of-flatness. Currently, the design equations for shear in plate girder web panels in the American Association of State Highway and Transportation Officials (AASHTO) and the American Institute of Steel Construction (AISC) specifications account for beam action shear buckling strength and post-buckling strength separately and combine these resisting capacities based on the aspect ratio of the web panels. Although equations in these specifications predict the overall shear strength with reasonable accuracy, they often underestimate the beam action shear buckling strength, due to an underestimation of the rigidity at the flange-web juncture, and often overestimate the post-buckling strength of certain web panels, as a result of excluding the effect of out-of-plane bending stresses. Based on a parametric study of numerical results, new design equations are proposed for the determination of ultimate shear strengths of web panels. To validate these equations, ultimate shear strengths computed from the equations are compared with existing experimental data. From the parametric study of the data generated by the nonlinear finite element analyses presented, a set of new design equations has been formulated. Comparative studies demonstrate that the proposed design equation can accurately predict the ultimate shear strength of plate girder web panels. These design equations have been validated by a series of comparative studies, including the comparison with existing test data as presented in the paper. It concludes that,

- For web panels having low web slenderness ratios, the ultimate shear strength reduces significantly as the initial distortion increases.
- Based on analyses of a large number of web panels with large initial distortions close to the maximum allowed by the ANS / AASHTO / AWS D1.5-96 Bridge Welding Code (1996), equations to determine the strength reduction have been formulated.

2. **N. E. Shanmugam and K. Baskar, J (2003)** in their paper titled **"Steel-Concrete composite Plate Girders subjected to Shear loading"** discusses on Steel concrete composite plate girders subjected to shear loading. Four composite and two bare steel plate girders were tested to failure in order to study their ultimate strength behaviour. The effect of composite action with the concrete slab on tension field action in the web panels is the main focus of the study. Extensive strain measurements were made on the web panels in order to measure the extent of tension field action. It is observed from the tests that the ultimate shear capacity of composite plate girders increases significantly compared to bare steel girders. The test specimens were analyzed using finite element modelling and the predicted results compared with the corresponding experimental values. The comparison shows good agreement thus confirming the accuracy of the modelling. A detailed experimental study was carried out on composite plate girders subject to primarily to shear loading to study the variation in the tension field action of the web plate due to composite action with the deck slab. The conclusions based on the experimental work includes as follows:

- Composite action enhances the effectiveness of web plate to resist larges shear
- The width of the yielded tension band increased due to composite action of the deck slab
- Composite action is more significant in the case of plate girders with a larger d/t ratio
- Significant enhancement was also observed in the load carrying capacity of composite plate girders with a smaller d/t raio

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- Shear links also altered the mode of failure from shear to flexure and leads further to more or less ductile failure after the ultimate load.

3. **A. Cevik (2006)** in his paper titled **"A new formulation for longitudinally stiffened webs subjected to patch loading"** proposes a new formulation for longitudinally stiffened webs subjected to patch loading using Genetic programming. The database for the proposed formulation is based on the experimental results from the literatures. Those obtained results were compared with existing models and design codes. Extensive experimental research has been conducted all around the world on the effect of longitudinal stiffening subjected to patch loading resistance has been reviewed. The patch load resistance are related to several models such as Regression models, Failure mechanism model, Post critical resistance approach, Design procedure in BS 5400, Neural network and neuro fuzzy models. Among the various experimental data from the literatures, 138 sets were used for GP training and 24 set for GP testing. The design parameters are thickness of the web, stiffener spacing, depth of the web, thickness of the flange, breadth of the flange, thickness of stiffener, breadth of stiffener and distance between panels. The proposed research concludes that,

- The GP formulation shows perfect agreement with experimental results.
- For comparative analysis, numerical results of the same experimental database are obtained by existing design codes BS 5400 and models and the proposed GP formulation is found to be more accurate.
- The GP formulation also considers the effects all parameters on the ultimate resistance of steel girder webs subjected to patch loading which has not been considered in existing models and design codes so far.

4. **Donald W. White, and Michael G. Barker (2008)** in their paper titled **"Shear resistance of Transversely Stiffened Steel I-Girders"** have done research on shear Resistance of transversely stiffened Steel I Girders. This paper evaluates the accuracy and ease of use of 12 of the most promising models for the shear resistance of transversely stiffened steel I-girders. Several models that are well established in civil engineering practice as well as a number of other recently proposed models are considered. As the model developed in Basler's seminal research is the method of choice in current American practice, the paper focuses on the merits and limitations of the alternative models relative to Basler's. Statistical analyses are conducted on the predictions by the various models using an updated data set from 129 experimental shear tests, including 30 hybrid and 11 horizontally curved I-girders. The results support the conclusion that the form of Basler's model implemented in 2004 AASHTO LRFD Bridge Design Specifications and 2005 AISC Specification for Structural Steel Buildings gives the best combination of accuracy and simplicity for calculation of the shear resistance of transversely stiffened steel I-girders. The Conclusions are as follows:

- The Basler model implemented in the AASHTO (2004) and AISC (2005) specifications provide the best combination of accuracy and simplicity of the models considered for the calculation of the shear resistance of transversely stiffened I-girders.
- The Cardiff model is the most accurate of these models, but requires substantially more calculation.
- The more accurate shear buckling coefficient, tends to give a minor improvement in the dispersion of V_{test}/V_n for both the Basler and the Cardiff models.

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ISSN 2348 - 7550

5. **Chris R. Hendy, Francesco Presta(2008)** in their paper titled **"Transverse web Stiffeners and shear moment interaction for steel Plate Girder bridges"** studied about the behavior of Transversally stiffened plate girders in bending and shear using non linear finite element analyses has been done by The design rules for the transverse web stiffeners are based on EN 1993-1-5. The true behavior of stiffened plate girders in shear and bending were observed using a FE software package LUSAS. Two types of beam geometry were considered: Symmetrical steel girder and Steel-concrete composite girder. The Design variables are Panel aspect ratio, Elastic critical shear stress, Critical shear force, Ultimate shear. In case of symmetrical steel girder, the lateral deflection of the web at failure is illustrated. The girder failed by the web bowing out laterally and yielding, while the stiffeners twisted in sympathy but did not themselves cause the ultimate failure. The girders showed an extra resistance about 15% when compared to the Eurocode. An extreme situation was also investigated where the stiffener A was removed and replaced with a line support. They claims that the girder still achieves a shear even if the stiffener cannot carry any axial force since out of plane bending stiffness is more important than axial resistance. Similarly it was carried out for steel-concrete composite girder. The shear moment behavior and the resulting stiffener forces were examined with the effect of varying the strength and stiffness of the stiffeners. They concludes that,

- The FE modeling for both type of girders shows that the overall failure was not due to the local stiffener failure as long as the stiffener's stiffness was in accordance with the minimum requirement of EN 1993-1-5.
- Its yield strength was the same or greater than that of the web panel.
- The Eurocode prediction for overall girder strength was always safe.
- The axial stree in some cases had an influence on the final load bearing resistance of the girder as one would expect, but had limited effect on the stiffener forces.
- The effects of different Shear moment ratios were investigated and compared. The results of EN 1993-1-5 were found to be conservative.
- Girder resistances were relatively insensitive to initial imperfections in the stiffeners and web panels.

6. **Donald W. White, Michael G. Barker, and Atorod Azizinamini (2008)** in their paper titled **"Shear strength and moment-shear interaction in Transversely Stiffened Steel I-Girder"** discusses on Shear Strength and Moment shear interaction in transversely stiffened steel I-Girders. This paper presents the results from the collection and analysis of data from a total of 186 high-shear low-moment, high-shear high-moment, and high-moment high shear experimental I-girder tests. References to corroborating refined finite element studies are provided. Particular emphasis is placed on the extent to which web shear tension-field strength is developed in hybrid I-girders, as well as on the interaction between the flexural and shear resistances in hybrid and non-hybrid I-section members. The results of the study indicate that, within certain constraints that address the influence of small flange size, Basler's shear resistance model can be used with the flexural resistance provisions of the 2004 AASHTO and 2005 AISC specifications without the need for consideration of M – V strength interaction. Also, the research shows that a form of the Cardiff model can be used with these flexural resistance provisions without the need to consider M – V strength interaction. These conclusions apply to both non-hybrid

and hybrid I-girder designs. Particular emphasis is placed on the extent to which web shear post buckling (tension-field) strength is developed in hybrid I-girders, as well as on the M-V strength interaction in hybrid and non hybrid I-section members. The high-shear high-moment and high-moment high-shear girders considered in this paper are predominantly tests in which the web yield strength is smaller than the yield strength of one or both flanges by one steel grade.

7. **M.M. Alinia, Maryam Shakiba, H.R. Habashi (2009)** in their paper titled **"Shear failure Characteristics of Steel Plate girders"** have studied the shear failure characteristics of steel plate girders. Their main focus is to study about the clarification of how when and why plastic hinges emerge in experimental tests actually form. It is also found that the shear induced plastic hinges only develop in the end panels. These hinges are caused by the shear deformations near supports and not due to bending stresses arising from tension fields. Also they have presented a comparison between the ultimate capacity of various plate girders and different codes and theories are presented. In order to study that, several transversely stiffened plate girders were modelled in ABAQUS software. And the parametric studies related to the web thickness, flange dimensions and end-posts were carried out. The results were discussed on Shear Vs Flexural plastic hinges, its failure modes, Shear induced plastic hinges, Effect of end-post/stiffeners, occurrence and location of plastic hinges. The Non linear large deflection finite element analyses to characterize their shear failure mechanism concludes that:

- Detached plates simulation does not represent the true behaviour of plate girder web panels.
- Shear induced plastic hinges occur only in the flanges of end panels after the formation of partial inclined yield zones in webs. They do not occur in mid-panels.
- The formation of plastic hinges is due to the shear deformation of girders, directly pertained to the stiffness of end posts and flange dimensions.
- The location of plastic hinges is not directly related to the stresses imposed by the inclined tension fields.
- When the flange thickness is more than three times the web thickness, the failure mode is always in shear. If it is less than two, the flexure failure governs. In the intermediate range, the failure mode depends on the web slenderness ratio.
- Compact webs collapse in flexural mode, while slender webs fail in shear.
- The addition of end posts provides more fixity to flange plates and increases the ultimate resistance of plate girders.
- Eurocode 3 gives the most conservative ultimate capacity for plate girders while the Porter's model over estimates them.

8. **France Sinur, Darko Beg(2012)** in their paper titled **"Moment-shear interaction of stiffened Plate Girders-Tests and numerical model verification"** discusses the moment-shear interaction of stiffened plate girders. The stiffeners were arranged in both the direction. In longitudinal direction, the web was stiffened with open or close stiffeners positioned in the compression zone. Detailed information on initial geometric imperfection and residual stress are also given. The experimental results were used to verify numerical model. Then the resistance is compared against reduced stress method (RSM) and effective width method (EWM) based on EN 1993-1-5. The experimental work was carried out to

examine the characteristics of longitudinally stiffened plated girders under high bending and shear load. The stiffeners of the plate influence the amplitude of residual stresses and initial imperfections. Due to welding large initial geometric imperfection and small residual stresses are expected for slender web plates. A nonlinear FE analysis was carried out using ABAQUS. The theory of finite strains was implemented in nonlinear analysis. The load deflection curves obtained from numerical simulations are compared against curves obtained from the test. The strength obtained in FEM analysis is comparable to that of the test. The experimental results were also compared with the code provisions where the method can lead to very conservative results when one of the slenderness prevails. The load carrying capacity was calculated according EWM and RSM method. The EWM method gives more consistent results than the RSM method when compared to the test results. The reason why the resistance according to EWM is smaller because, the interaction of tension stresses and shear stresses in the subpanel is not covered. The authors concludes as follows:

- The rules given in the Eurocode is proved to be conservative for the tested configurations of plated girders.
- The resistance of girders calculated with the RSM method is smaller by 3% to 30% compared to the test results
- The verified model is used for further parametric study considering the behavior of plated girders under Moment shear interactions and to evaluate the reliability of different resistance models.

9. **France Sinur, Darko Beg (2012)** in their paper titled **"Intermediate Transverse Stiffeners in Plate Girders"** has carried out the study of design requirements for rigid intermediate transverse stiffeners in longitudinally stiffened plate girders. Comparison of Experimental work and Analytical work using ABAQUS has been carried out. The two representative design standards, AASHTO and EN 1993-1-5 were discussed. For comparison of results, an experimental work has been carried out. Two tests were conducted on intermediate transverse stiffener. The experimental and numerical results were compared by way of the load deflection curves. The initial stiffness of numerical model is slightly higher that the experimental one. A parametric study has also been carried out using variables like Height & thickness of web, Spacing b/w stiffeners, Breadth & thickness of flange, Height, Breadth & thickness of stiffeners. When considering the axial force, it is overestimated in the stiffener which is considered to be important for the single sided stiffeners mostly used for intermediate transverse stiffeners. The paper infers that

- The required performance of rigid intermediate transverse stiffeners of longitudinally stiffened plate girders may be obtained by fulfilling the stiffness criteria in EN 1993 1-5.

10. **R. Chacon, E. Mirambell, E. Real (2013)** in their paper titled **"Transversely Stiffened plate Girders subjected to Patch loading"** have done research on the Structural response of transversally stiffened plate girder subjected to patch loading. They have presented an experimental work of six steel plate girders subjected to patch loading and fory eight numerically tested prototypes. In addition to that, experimental and numerical values of ultimate load capacity are also compared based on EN 1993-1-5. The numerical modeling was carried out using FE based software ABAQUS. Non linearity analysis was performed on steel plate girders loaded upto failure in a concentrated manner. The results are validated based on the Eurocode EN1993-1-5. The Design Variables are Height & Thickness of web, Width of

web panel, Distance of long stiffener from flange, Stiff bearing length, Thickness of flange & stiffeners. A good agreement between the experimental and numerical results was obtained. The previously performed 48 simulations were subjected to centrical patch loading. The structural response was captured beyond the peak load. The observations showed considerable discrepancies between both numerical and theoretical predictions. As a part of results the values of the ratio between the numerically obtained ultimate load and the predicted ones were shown. The Paper concludes that,

- The girders with largely spaced transverse stiffeners present a considerably different response from girders with closely spaced transverse stiffeners.
- The failure mode of largely spaced stiffeners is mainly governed by folding of web panel with no contribution of the flange moment capacity.
- The failure mode of closely spaced stiffeners seems to be partially governed by the web, the loaded flange and the transverse stiffeners.
- Experimental and numerical results on ultimate load capacity differ considerably fro EN 1993-1-5 predictions for girders in which the transverse stiffeners are closely spaced.

IV. CONCLUSION

The purpose of this paper is to review the various techniques in optimization of stiffened plate girders within the past 20 years and see the changes in evolution of trends in optimization. It is clear from the research reviewed that the optimization has been widely practiced throughout this field and it is still in progress in search for the new trends in optimization. In the midst of optimization techniques various software packages are adopted for the various optimization problems which results in various approach on results. Researches involving the experimental works on plate girders have helped in identifying various parameters that are helpful in investigating those specific plate girders involved in optimization areas. Every Optimization technique has its own merits and demerits, but from the literatures reviewed it can be concluded that Genetic Algorithm is an efficient tool that can be used for solving optimization problems of plate girders.

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