International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 02, February 2016
www.ijirse.com
ISSN: 2454-9665

A REVIEW OF OPTIMIZATION OF PLATE GIRDERS WITH CORRUGATED WEBS

A. Annie Pauline Sarah[1], Priya A. Jacob[2]

[1]Student, [2]Assistant Professor, Structural Engineering, Karunya University, (India)

ABSTRACT

The corrugated steel plate is a widely used structural element in many fields of application because of its numerous favorable properties. The corrugated web beam behavior, the bending moments and applied forces are transferred only via the flanges, while the transverse forces are only transferred through the corrugated web. The use of corrugated web beams has been increasing in the recent years owing to improvements in the automated fabrication process of corrugated steel plates and the reduction in weight. The main advantage of plate girders over hot rolled I girders is the flexibility in the dimensions of the girder. Optimization of the girders is necessary for to take complete advantage of this asset. This paper presents a review of various studies on plate girders with corrugated webs and optimization of plate girders.

Keywords: Corrugated web, Optimization, Plate Girders.

I. INTRODUCTION

Plate girders are built-up flexural members. They consist of steel plates which may be welded or bolted together to form a deep beam larger than can be produced by rolling. As such, it is capable of supporting greater loads on longer spans. The typical welded plate girder consists of flange plate welded to a deep web plate. A bolted configuration consists of flanges built of angles and cover plates bolted to the web plate. Plate Girders may have vertical stiffeners connected to the web plate. Corrugated web Plate Girders are built-up girders with a thin-walled, corrugated web and wide plate flanges. The profiling of the web generally avoids failure of the beam due to loss of stability before the plastic limit-loading for the web is reached. Generally , trapezoidal and sinusoidal profiles are used. The thin web corrugated web beams afford a significant weight reduction compared with hot rolled profiles or welded I-sections. Buckling failure of the web is prevented by the corrugation. The buckling resistance of corrugated webs is comparable with plane webs smaller thickness. Due to improvements of the automatic fabrication process corrugated webs up to 6 mm thickness became possible. Therefore the field of application of this beam type has been extended considerable. Even short span bridges are possible now. In the last years many tests and finite element simulations have been carried out. Splices are required for webs and flanges when the span of the Plate Girders exceeds the manufactured lengths of the plates.

II. NEED FOR OPTIMIZATION

The main advantage of the use of plate girders over rolled steel sections is the flexibility in the dimensions of the girder. To take maximum advantage of this asset optimization is necessary. Optimization in the design is a trial and error method and is a very tedious process. Hence arises the need for the development of an optimization tool. The optimization tool must be able to work within various constraints to be suitable for the optimization of plate girders.

III. LITERATURE REVIEW

3.1 Optimization of Plate Girders

Abuyounest et al proposed a method for the optimization of hybrid steel plate girders using general geometric programming technique.

The multi-term polynomial was condensed to form a standard polynomial problem which was transformed into an equivalent linear programming problem by natural logarithmic transformation. The constraints were expressed in a suitable form for application in the general geometric programming. The formulation was developed considering various possibilities such as types of lateral support, stiffeners and load. The design variables included the dimensions if t elements. The design parameters included the yield strength of the web, flange and stiffeners, bending moment, shearing force and the laterally unsupported length. The objective function was formulated for both stiffened and unstiffened plate girders. The design constraints were formulated based on AISC specifications. This method was applied to a few problems and was observed to be an efficient method for the optimization of plate girders.

Adeli et al developed an interactive optimization platform for the optimization of multispan plate girders using general geometric programming implemented in FORTRAN 77.

The primal problem which was non linear was transformed into an equivalent linear problem by double condensation. The objective function was formulated as the total weight of the girder assuming uniform cross section throughout the length of the girder. The design and the formulation of constraints were based on AISC specifications.

The program developed contained the main menu and the display menu to read, edit, optimize and display the loading and elevation. The problem is first specified and displayed to enable checking and editing. The dimensions of the cross section are initially specified or generated by the program. The structure is analyzed and the GGP technique is used to solve for the design variables. When the primal constraints are not satisfied, the most violated constraint is condensed and added to the original design constraint and then preceded. When the primal constraints are satisfied and the iterative optimization is continued until two consecutive designs vary within the tolerance. This formulation was applied to problems with various spans and homogeneity and was observed to be a useful tool for the optimization of plate girders.

Balaur et al presented a formulation for the optimum design composite hybrid plate girders using generalized geometric programming technique.

The optimization involves the minimization of the total weight of the girder under behavior and design constraints. This problem is associated with high non-linearity which is acceptably dealt with generalized geometric programming. The GGP problem is approximated to a GP problem which is transformed to an equivalent linear programming problem by condensation and natural logarithmic transformation.

The load factor method in the AASHTO 1983 specifications was used for the design formulation. The bottom flange was assumed to be of higher strength and the stiffeners were assumed to be placed on one side of at equal spacing. The independent variables included the cross sectional dimensions of the girder. The design parameters included the yield strength of the elements, length of the girder, compressive strength and modular ratio of the concrete. The formulation contained equality and inequality constraints which enforced limitations on the stresses and displacements. The method was implemented and validated in stiffened and unstiffened hybrid plate girders.

Memari et al presented the optimization of continuous steel plate girders using SPGBROD.

The choice of the method of optimization is based on its efficiency and suitability to the current problem. Further, efficient interfacing of the analysis and optimization must be ensured. The analysis was done by Finite Element modeling using SAP IV program and the optimization by CONMIN program. The structure was modeled using plate elements and prismatic beam elements, analyzed and designed at sections corresponding to positive and negative moment. The objective function was formulated in terms of cost. The inequality constraints corresponding to flexural strength, shear capacity, web and stiffener buckling and deflection were formulated according to AASHTO specifications. The expression for the maximum deflection was derived from the maximum positive moments and the negative support moments in the span in which the maximum deflection is expected to occur. A three-span three-girder bridge was optimized using this method and a reduction in the cost of 26 percent was observed. The optimization was observed to be more stable at initial costs higher than the minimum cost and the minimum cost obtained from various starting designs was observed to be fairly same with a maximum deviation of 4.3 percent.

Asghar Bhatti et al developed a method for the optimization of welded plate girders subjected to highway bridge loading. The procedure involved the analysis of the plate girders subjected to moving load and optimization of the weight of the girder constrained according to AASHTO specifications.

The formulation can be applied in a various cases involving variations in stiffening, shoring, symmetry and variation of depth and flange thickness along the span. The typical formulation was taken to be the unshored composite case and the other types were taken to be special cases of this case. The analysis was done by composite beam finite element analysis. The loads were estimated using Influence Line Diagram (ILD) in the case of live loads. The design load at a point on the girder is the algebraic sum of the composite dead loads, positive live loads and negative live loads. The optimization was done for minimum weight rather than cost to enable wider application of the formulation. The objective function was minimized constrained in bending stress, shear stress, slenderness ratio, deflection and depth according to AASHTO specifications. A typical case was optimized and it was observed that for a specified span, in comparison with the noncomposite design, the unshored composite design showed a 20 percent reduction in the weight and the shored composite design showed a 30 percent reduction in the weight. The shored composite design also showed a 25% reduction in the depth of the girder. This formulation enables optimization in terms of weight and the type of plate girder to be adopted.

Saeid A. Alghamdi developed an automated tool for the minimum weight design of plate girders. The code was developed for the Direct Search Method (DSM) and Generalized Reduced Gradient Method (GRGM) for the ASD and LFRD design specifications.

The objective function was formulated in terms of volume of steel constrained according to the AISC specifications in flexure and shear. The tool was applied for certain design cases and the efficiencies of the

Direct Search Method (DSM) and the Generalized Reduced Gradient Method (GRGM) were compared. A parametric study was also carried out. The DSM method was observed to be more economical than GRGM method with a reduction of 14 percent in the volume of steel. It was observed that the efficiency of the LFRD method was reduced with an increase in the plate thickness. The optimum range of values of the moment coefficient for the ASD and LFRD method were arrived at. The LFRD method was found to be more efficient for smaller values of the thickness of the flange and web plates. The versatility of the formulation in the usage of the LFRD and ASD methods allowed a wide range of application in providing an economical design accompanied by computational advantages.

Kuan-Chen et al presented the optimization of Plate Girder bridges using Genetic Algorithm. The concept of Elitism was included to overcome the disadvantage of reduced efficiency due to randomness of Genetic Algorithm.

The objective function was formulated in terms of cost, which included the material, fabrication and labor cost. The design inequality constraints such as the stress constraints, dimensional constraints and deflection constraints were formulated according to the AASHTO specifications. The constraints were transformed into an exterior penalty function for the application in Genetic Algorithm which is an unconstrained optimization technique. The maximum moments, shear force and deflection were obtained by placing the loads specified in the AASHTO code at appropriate locations. The population, number of crossover sites and probability of mutation were adopted based on efficiency of optimization and computation time. The randomness of the Genetic Algorithm caused occasional irregularities but a convergence to a proper solution was observed. The size of the web plate was observed to increase with an increase in the span of the girder. A steady increase in the area of the flange plate with the span of the girder was also observed. The optimum ranges of values for the design parameters for a specified span were obtained. The Genetic Algorithm was observed to be an efficient method in handling discrete variables.

Faluyi et al applied generalized reduced gradient method in excel solver and constrained artificial bee colony algorithm in the optimization of plate girders.

In the generalized reduced gradient method the constrained problem is transformed into an unconstrained problem by direct substitution. The artificial bee colony algorithm used Deb's constraint handling technique for application in constrained optimization. The design variables included fixed values such as the span of the girder and the yield strength of the steel and variables including the cross sectional dimensions of the plate girder. The objective function is the weight of the plate girder constrained in dimensions, sectional classification, moment of resistance, shear capacity and serviceability according to the provisions in BSI 2000. The optimization was carried out using generalized reduced gradient method and artificial bee colony (ABC) method resulting in the reduction of cross sectional area by 7.4 percent and 7.25 percent respectively. The results of the parametric studies revealed that the height of the web was the most influencing factor.

3.2 Experimental and Analytical Work on Plate Girders with Corrugated Webs

Mohamed et al studied worked on the estimation of shear strength of beams with corrugated webs.

Experimental investigation was carried out on two sets of beam specimens under three point loading. The first set of beams with intermittent welded connections failed at the web to flange connections before the ultimate strength of the beam was reached. The other set of beams were manufactured with continuous welding to make sure that the high stresses at the web to flange joints do not cause premature failure of the beams. The results showed that the densely corrugated webs failed by global buckling and scarcely corrugated webs failed by local buckling. Finite element analysis was carried out on beams with corrugated webs using the finite element software ABAQUS. The corrugated web was modeled using the eight-node thin-shell element and flanges and stiffeners were modeled using three-node Timoshenko beam element and analyzed. The finite element analysis was able to estimate the shear strength of the beams with an acceptable level of accuracy. The accuracy increased when the initial imperfections observed in the actual beam were incorporated in the finite element model.

Mohamed et al studied the bending behavior of steel girders with corrugated webs experimentally and numerically verified the results.

A total of six beam specimens varying in the corrugation profiles and dimensions were tested under three point loading. The corrugations were restricted to the region of uniform moment. The remaining length of the beam was braced and transverse stiffeners were provided to ensure bending failure of the beam in the region of constant bending moment. The beams were instrumented with strain gauges in the center of the panels and the deflections were recorded from the movement of the loading head of the testing machine by SATEC control system. The mode of failure in all the specimens was abrupt by yielding of the compression flange followed by vertical buckling into the web. The strains in the web away from the localized effect at the flange to web connection were negligible showing the absence of the contribution of the web in resisting the moment. This was also verified by comparison of the actual moment of resistance obtained experimentally with the theoretical moment of resistance by flange area method. A nonlinear analysis was carried out using the finite element software ABAQUS on the beams which were modeled using the elements eight-node quadrilateral and six-node triangle. A good agreement was observed between the results of the experimental and numerical investigation. Parametric study showed that the ultimate moment capacities were not affected by the material of the web, corrugation configuration and the panel aspect ratio.

Khalid et al investigated the bending behavior of beams with corrugated webs experimentally and numerically.

The experimental investigation consisted of testing beam specimens with webs containing single horizontal corrugation, two horizontal corrugations and vertical corrugations under three point bending. The corrugations were formed by consumable arc welding of equally split pipes. The influence of the weld on the behavior of the beams was reduced by restricting the number of layers of weld to one. The material properties were determined by testing of coupons collected from the beams. The test rig was set up in a Universal Testing Machine (UTM) and the load was applied by automatic displacement control method at a moderate loading speed to reduce the chances of a sudden failure. The beams with the webs corrugated in the vertical direction were observed to have higher bending capacity of up to 32.8 percent higher than the plane and horizontally corrugated web beams. The beams tested experimentally were modeled in a finite element software using quadrilateral thick shell elements and analyzed. The material properties obtained from the experimental study were incorporated. Owing to various factors such as amount of welding in the joints and heat produced during welding resulted in a difference in values of up to 28.37 percent from the experimental results. A change in the material of the web was observed to increase the moment carrying capacity of the beam up to 16.05 percent against 10.09 percent from the change in the material of the flanges.

Sherif et al studied the behavior of composite girders with corrugated webs under monotonic and cyclic loading. The experimental investigation was validated and studied numerically and analytical technique for the estimation of fatigue life of the girders was proposed based on fracture mechanics.

The experimental investigation consisted of testing six plate girders with trapezoidally corrugated webs under four point loading. The specimens were initially tested under static load of 120 percent of the maximum repeated load to be applied. The deflections and strains were measured to obtain the response to the static load. Higher stresses were observed in the parallel folds than in the inclined folds. Fatigue loading was applied with the minimum load starting from 10 percent of the ultimate capacity and the maximum load up to 60 percent of the yield load. During the test, visual inspection of the welds at expected areas of stress concentration was carried out. The fatigue life of plate girders with corrugated webs was observed to be higher than that of stiffened plate girders up to 78 percent. Further detailed study and validation was done by finite element analysis using ABAQUS. The girder was modeled using quadrilateral and triangular elements with five degrees of freedom. It was observed that a single-corrugation model with loads applied as tension and compressive forces was sufficient to simulate the behavior of the entire plate girder. The analysis indicated a stress concentration at the base of the fold line which reasons out the failure mode. It was observed that the ultimate load and the stress concentration factor decreases with an increase in the radius of curvature of the fold line, the stress concentration factor being the most influenced. The influence of the angle of inclination of the weld toe on the shear concentration factor was studied and a relation was developed. The test results were verified and an expression for the estimation of the fatigue life was developed using linear elastic fracture mechanics analysis.

Richard et al experimentally studied the fatigue behavior of plate girders trapezoidal corrugated webs.

The experimental investigation involved testing of large-scale specimens for reliability in real time structures in terms of fatigue life. The geometrical configuration of the test specimens were arrived at based on previous literature based on shear and fatigue considerations. The specimens were tested under four point bending by the application of fatigue load by two synchronized jacks within the specified stress range. The tests were terminated at the final stage of propagation of the cracks to the flange tip. The fatigue life of the robotically welded girder was observed to be higher than the semiautomatic welded girder by 42 percent. The general mode of failure was the initiation of cracks at the weld toe along the inclined web and finally propagation to the tip of the flange. The fatigue life of the plate girders with corrugated webs was observed to be longer than that of plate girders with transverse stiffeners but shorter than that of unstiffened plate girders with flat webs.

Robert et al studied the shear behavior of plate girders with corrugated webs. The existing concept using plate buckling theory for shear buckling of the web was verified using existing theoretical data and revised for initial imperfections in the web panels. The theoretical concept was verified by experimentally and analytically.

The shear strength of the corrugated web girder in local and global buckling modes was estimated theoretically by plate buckling theory. Comparison with existing experimental data, showed that the shear strength was overestimated at small values of slenderness ratios. The initial imperfections in the web were observed to affect the shear strength and thus had to be considered in the theoretical estimation of shear strength. The effect of the initial imperfections was analyzed by FEM analysis and a reduction in strength of 23 percent was observed.

Experimental investigation was carried out on full scale plate girders measuring the initial imperfections and the behavior was observed to be as predicted by the FEM analyses and the theoretical concept predicted the shear strength conservatively.

Ezzeldin studied the design aspects of plate girders with corrugated webs theoretically and numerically.

The failure of the plate girders with corrugated web under shear may be due to yielding of the web or buckling of the web, globally or locally. The girders were modeled in ANSYS using isoparametric 8-node shell element and nonlinear analysis was carried out. The results of the FEM analysis were in good agreement with the theoretical interaction equation proposed. The post buckling strength was observed to be significant in webs with larger panel widths. The critical moment for the initiation of lateral torsion buckling in plate girders with corrugated webs was greater than that of plate girders with plane webs by up to 37 percent. It was observed that the local buckling behavior of the flange predicted theoretically by considering the larger flange outstand coincided with the numerical results. The contribution of the corrugated web to the moment capacity of the girder was observed to be insignificant.

Jongwon et al studied the shear buckling behavior of trapezoidally corrugated steel webs.

The local and global buckling failures were predicted by classical plate theory and orthotropic plate buckling theory respectively. An expression foe the interactive shear buckling failure was proposed. The corrugated webs were modeled in a finite element program using thin shell elements and analyzed by elastic and nonlinear analyses. It was observed from the elastic analyses that the geometric parameters influencing the shear buckling mode and strength were the panel aspect ratio and the web slenderness ratio. Comparison of the theoretically obtained shear buckling strength with published experimental data showed that the proposed equations for the estimation of shear buckling stresses were able to conservatively estimate the actual shear buckling stresses of trapezoidal corrugated webs.

Jiho et al studied the shear strength behavior of corrugated steel webs and proposed an expression for the estimation of the shear strength. Experimental studies were also carried out for the validation of the theoretical concept.

An expression for the capacity of the corrugated webs in interactive shear buckling was derived based on the first order interactive equation of elastic states in the form of classical plate buckling theory. The interactive shear buckling coefficient was expressed as a function of the panel aspect ratio and shear buckling ratio. The results of the experimental investigation showed that the proposed equation conservatively estimated the shear strength of the corrugated steel webs. A condition for the maximization of the shear strength of corrugated webs was also proposed.

Divahar et al experimentally studied the lateral buckling behavior of steel beams with corrugated webs. The increase in the out of plane stiffness due to the corrugations in the web was demonstrated in this paper.

The experimental investigation was done on six specimens under two point bending. The specimens consisted of beams with plain and corrugated webs. Corrugation angles of 30 and 40 degrees were included. The beams were built up by intermittent welds. The loads were applied at a distance of one-third from the supports under load control mode. Linear Variable Differential Transformers (LVDT) and strain gauges were installed for the measurement of deflection and the readings were obtained by data acquisition system. The failure mode was observed to be shear buckling in beams with plain webs, local flange buckling followed by local shear buckling in beams with 45 degree corrugated webs and local flange buckling in beams with 30 degree corrugated webs. The beams with 30 degree corrugated webs were observed to have the highest load carrying capacity and lowest average deflection. It was also observed that shear failure was eliminated in the beams with corrugated webs. Lateral buckling tests were conducted on a similar set of six specimens and the values of the lateral buckling moment resistance were determined by the knee joint intersection method. The beams with 30 degree corrugated webs were observed to have the maximum lateral buckling moment resistance.

IV. CONCLUSION

The choice of the method of optimization is based on its efficiency and suitability to the current problem. Various methods of optimization suitable for the optimization of plate girders are discussed based on various literatures. The behavior of plate girders with corrugated webs under various support conditions and loading conditions have been discussed and the optimum configuration of the corrugated web based on experimental and analytical studies have been discussed. Optimizing the dimensions of corrugated plate girders can help designers and researchers in achieving economical designs. In this regard, methods for the optimization of plate girders with corrugated webs are to be developed to enable the usage of plate girders with corrugated webs in real time structures.

REFERENCES

[1]. A.M.Memari and H.H.West, Optimization of continuous steel plate girder bridges, Structural Optimization 3, 231-239 , 1991.

[2]. Balaur S. Dhillon,1 Fellow, ASCE, and Chen-Hsing Kuo, Optimum Design Of Composite Hybrid Plate Girders, Journal of Structural Engineering, Vol. 117, No. 7, July, 1991.

[3]. Ezzeldin Yazeed Sayed-Ahmed, Design aspects of steel I-girders with corrugated steel webs, Electronic Journal of Structural Engineering7, 2007

[4]. F.Faluyi and C.Arum, Design Optimization of Plate Girder using Generalized Reduced Gradient and Constrained Artificial Bee Colony Algorithms, International Journal of Civil Engineering, Volume 2, Issue 7, July 2012.

[5]. H. Adeli and K. Chompooming, Interactive Optimization of Multispan Plate Girders, Microcomputers in Civil Engineering 3, 227-244 (1988)

[6]. Jiho Moon, Jongwon Yi, Byung H. Choi ,and Hak-Eun Lee, Shear strength and design of trapezoidally corrugated steel webs, Journal of Constructional Steel Research 65 1198_1205, 2009.

[7]. Jongwon Yi, Heungbae Gil, Kwangsoo Youm, Hakeun Lee, Interactive shear buckling behavior of trapezoidally corrugated steel webs, Engineering Structures 30 1659–1666, 2008.

[8]. Kuan-Chen Fu, Yujia Zhai, and Saijun Zhou, Optimum Design of Welded Steel Plate Girder Bridges Using Genetic Algorithm with Elitism, Journal of Bridge Engineering, Vol. 10, No. 3, May 1, 2005.

[9]. M. Asghar Bhatti and A.S. Al-Gahtani, Optimum design of welded plate girders

[10]. subjected to highway bridge loading, Transactions on the Built Environment vol 13, 1995.

[11]. Mohamed Elgaaly, Anand Seshadri,z and Robert W. Hamilton, Bending Strength Of Steel Beams With Corrugated Webs, Journal of Structural Engineering, Vol. 123, No.6, June, 1997.

[12]. Mohamed Elgaaly, Robert W. Hamilton, and Anand Seshadri, Shear Strength Of Beams With Corrugated Webs, Journal of Structural Engineering, Vol. 122, No.4, April, 1996.

[13]. R.Divahar, P.S.Joanna, Lateral Buckling Of Cold Formed Steel Beam With

[14]. Trapezoidal Corrugated Web, International Journal of Civil Engineering and Technology, Volume 5, Issue 3, March 2014.

[15]. Richard Sause, Hassan H. Abbas, Robert G. Driver, Kengo Anami and John W. Fisher, Fatigue Life of Girders with Trapezoidal Corrugated Webs, Journal of Structural

[16]. Engineering, Vol. 132, No. 7, July 1, 2006.

[17]. Robert G. Driver, Hassan H. Abbas, and Richard Sause, Shear Behavior of Corrugated Web Bridge Girders, Journal of Structural Engineering, Vol. 132, No. 2, February 1, 2006.

[18]. S. Abuyounest and H. Adeli, Optimization Of Hybrid Steel Plate Girders, Computers & Structures Vol. 21, No. 5, 1987.

[19]. Saeid A. Alghamdi, Design optimization of non-uniform stiffened steel plate

[20]. Girders-a computer code, Advances in Engineering Software 34, 357–386, 2003.

[21]. Sherif A. Ibrahim, Wael W. El-Dakhakhnib\, Mohamed Elgaaly, Behavior of bridge girders with corrugated webs under monotonic and cyclic loading, Engineering Structures 28 1941–1955, 2006.

[22]. Y.A. Khalid, C.L. Chan, B.B. Sahari, and A.M.S. Hamouda, Bending behaviour of corrugated web beams, Journal of Materials Processing Technology 150 242–254, 2004.