SHEAR BUCKLING OF TRAPEZOIDAL WEB PLATE

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ABSTRACT

One of the issues raised since the steel structure was introduced in the construction industry is how to reduce the weight and the cost of the component parts such as girder and beams. Economical design of girders and beams normally requires thin webs. But if the web is extremely slender the problem of plate buckling may arise. Possible ways to reduce this risk are by increasing the thickness of the web plate, adding web stiffeners or strengthening the web by making it corrugated. Recently, by the advances in welding technology, the idea of using beams with corrugated web as an alternative to save cost has been investigated. In the absence of any specific design guide, the British Standard BS5950 can be used as the basis for the design of the corrugated beams and girders. But can we then assume that using the BS5950 for the corrugated web girders would result in an economic design? To develop a new design guide specifically dedicated to trapezoidally corrugated sections, research is being carried out in the Department of Structures and Materials, University Teknologi Malaysia. One of the major scopes is the determination of shear buckling capacity of the web panel. The objective of the research is to study the behaviour of trapezoidally corrugated web plate girder under shear force. A series of laboratory tests have been carried out on the girders with corrugated sections subjected to predominantly shear loading and a series of finite element analyses using LUSAS software is used to study the critical elastic shear buckling of the web of various slenderness ratios. The results of the research are then used for the design calculation of the section properties. An empirical formula to calculate critical shear stress proposed at the end of the study. The shear capacity of the trapezoid web plate girder could be calculated using the proposed formula.

ABSTRAK

Salah satu isu yang wujud sejak struktur keluli diperkenalkan di dalam industri binaan adalah untuk mengurangkan berat dan perbelanjaan dari bahagian-bahagian component seperti plat galang dan rasuk. Rekabentuk yang ekonomi dari plat galang dan rasuk secara amnya memerlukan plat yang langsing. Tetapi apabila plat tersebut terlalu langsing masalah lendingan pada plat akan wujud. Cara yang paling mungkin untuk mengurangkan risiko ini iaitu dengan mempertebal plat web, menambah pengaku web atau memperkuat web dengan menjadikannya bergelombang. Sekarang ini, dengan kemajuan teknologi pengimpalan, idea menggunakan rasuk dengan plat web bergelombang menjadikannya pilihan yang terlebih baik untuk menjimatkan perbelanjaan sudah dapat dibuat. Kerana ketiadaan piawaian untuk merekabentuk, British Standard BS5950 masih dapat dipergunakan sebagai asas di dalam merekabentuk rasuk dan plat galang yang menggunakan plat web bergelombang. Tetapi bolehkah kita mengandaikan bahawa dengan menggunakan BS5950 untuk plat galang dan rasuk dengan plat web bergelombang ianya menghasilkan keputusan rekabentuk yang ekonomi? Untuk membina satu panduan rekabentuk yang sesuai bagi *trapezoidally corrugated web,* penyelidikan sedang dijalankan di makmal Struktur dan Bahan, Universiti Teknologi Malaysia. Salah satu skop utama adalah mengenalpasti keupayaan lendingan ricih dari web panel. Matlamat penyelidikan ini adalah untuk mempelajari sifat dari plat galang yang mempunyai plat web bergelombang yang dikenai beban ricih. Satu siri pengujian di makmal telah dijalankan terhadap pelat galang dengan keratan yang bergelombang dengan pembebanan ricih dan analisis berkaedah unsur terhingga telah dilakukan menggunakan perisian LUSAS untuk mempelajari lendingan ricih kritikal dari plat web dengan berbagai nisbah kelangsingan. Di penghujung kajian yang dilaksanakan, satu formula pengiraan untuk menjangka keupayaan tegasan ricih pada plat web bergelombang diperkenalkan. Keputusan dari penyelidikan ini kemudian digunakan di dalam pengiraan rekabentuk dari sifat-sifat keratan.

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NOTATIONS

B	-	Width of flange
D	-	Overal depth of girder
b	-	Horizontal width of sub panels of a corrugation fold
d	-	Depth of corrugated web
h_r	-	Depth of the corrugation
t	-	Thickness of web
T	-	Thickness of flange
D_x	-	Bending stiffness per unit length about x-axis
D_y	-	Bending stiffness per unit length about y-axis
E	-	Young's modulus
f_y	-	Yield stress
I_{yw}	-	Moment inertia (web only) about the minor axis
k	-	Buckling coefficient
V	-	Applied shear force
V_d	-	Designed shear force base on local buckling
γ_l	-	Reduction factor for local buckling
γ_g	-	Reduction factor for global buckling
$\bar{\lambda}_{p,l}$	-	Qualitative degree of slenderness for local buckling
$\bar{\lambda}_{p,g}$	-	Qualitative degree of slenderness for global buckling
θ	-	Angle of corrugation profile
μ	-	Poisson's ratio
τ_y	-	Shear stress equal to 0.6 f_y
τ_d	-	Design ultimate shear stress
τ_l	-	Critical local buckling stress
τ_g	-	Critical global buckling stress

τ_i	-	Interactive buckling stress
$\tau_{pi,l}$	-	Ideal buckling stress which influenced by edge stress for local buckling
$\tau_{pi,g}$	-	Ideal buckling stress which influenced by edge stress for global buckling

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CHAPTER I

INTRODUCTION

1.1 Introduction

Welded plate girders, which is constructed from welded steel plate, has been well recognised for the design of long span beams or beams carrying high loading. One of the main issues in the steel structure raised since the steel structure designed is the need to reduce the weight and the cost of the component parts. Economical design of girders and beams normally requires thin webs. But if the web is extremely slender the problem of plate buckling may arise. Possible ways to reduce this risk are by using thicker plates, add web stiffeners or the latest innovative technique by strengthening the web by making it corrugated.

The conventional welding of stiffeners to allow the use of thin webs has two disadvantages i.e. high fabrication cost and a possible reduced life due to fatigue cracking that may initiate at the stiffener weld. The use of corrugated plates to replace the stiffened flat plates for the web of a girder can eliminate both disadvantages [1]. Through the advances in welding technology, fabrication of sections with corrugated web has been made easy.

A numbers of testing programs have been conducted by previous researcher to find the best way to utilise corrugated webs. Studies on the behaviour of beams with corrugated webs subjected to shear have been conducted since early 1960's but the full capacity of corrugated plates is still underestimated and only since 1980 has its behaviour been studied in detail [2, 3]. The corrugated plate is nowadays used for structural component in aircraft, ships, offshore structures, bridges and buildings. Corrugated webs used in beams and girder have been employed in bridges in France and Japan for several years and the corrugated steel web have found comprehensive application in long-span roof beams in Sweden.

In Malaysia the technology was introduced by Trapezoid Web Profile Sdn. Bhd. based in Pasir Gudang. Trapezoid Web Profile Sdn. Bhd., a subsidiary of the Johor Heavy Industries Group of Companies, was incorporated on 25th September 1995 as part of the policies to diversify its activity into manufacturing of trapezoidal web profile (TWP) girders for construction.

To ensure the acceptance of this new structural component and for the purpose of design, continuous research in various fields and application are being carried out. In absence of any specific design guide, the British Standard BS5950 can be used as the basis for the design of the TWP beams and girders. However, there is no special provision for corrugated section in BS5950. Therefore, a number of simplification and conservativeness have to be made when using BS5950 for the corrugated web. It subsequently can lead to uneconomic in design.

In TWP girder, corrugated webs require no stiffening except at supports, so it permits the use of thinner plates with significant weight saving. Because of its high slenderness ratio, stability due to shear force should be concerned primarily. The purpose of this study is to examine the behaviour of trapezoid web girders under shear force. Experimental, analytical and numerical studies were conducted and described in this thesis.

1.2 Trapezoid Web Plate Girder

Trapezoid web system is a built up section made up of two flanges connected to a corrugated slender web. The web and the flanges can be made from different steel grade depending on design requirements. The flanges width and thickness are determined based on the depth of the section. This construction considerably improves the ratio of girder weight to performance compared to conventional hot-rolled girders. By using TWP girders with otherwise identical dimensions substantially less material is required and much greater span can be achieved with the same quantity of steel used. Figure 1.1 and 1.2 shows the shape and the dimension of section for trapezoid web system. The TWP beams and girders can be applied in the following areas:

(a) Industrial Building and Warehouse (see Figure 1.4).
(b) Bridge constructions for road and rail (see Figure 1.5 to Figure 1.7)
(c) Crane bridges crane ways and crane supports (see Figure 1.8)
(d) Floating constructions and offshore projects.
(e) Shipbuilding.

Some of the documented advantages in using corrugated webs are:

(a) Report on the construction of Maupre Viaduct Bridge as on Figure 1.6 in France that using TWP girders in conventional construction methods, larger clear spans can be achieved and producing cost save nearing 30 percents [3].
(b) With the advances in welding technology, automatic welding of corrugated webs can benefit from the joint tracking technology, and the web needs to be welded to the flanges only from one side. The cost of fabricating a girder with corrugated web is very economical when compared with conventionally stiffened girder [3].
(c) Due to the elimination of stiffeners and reduction in thickness of the webs, there should be a reduction in the weight. Spelten Consulting in Germany reported that the weight of beams and girders could be reduced by 30 to 60 percent [4].
(d) The use of corrugated webs will increase the lateral stiffness of the girder, thus minimise lateral-torsional buckling bracing requirements and the use of corrugated webs in composite construction will minimise cracking of the slab [5].

Research has shown that trapezoid web can withstand a bigger loading compared to conventional plate girder of the same dimension and spacing of stiffener. The Structural Steel Engineering Institute of the Technical University of Braunschweig has done some research and presented a comparison table, where the moment inertia, which the bending strength laid on this property, and its weight between British Steel, Perwaja Section, IPE and TWP beam were compared. The comparison is listed in Table 1.1.

1.3 Shear Strength of The Slender Web Plate Girder

Plate girders have employed to support heavy vertical loads over long span. In its simplest form the plate girder is a built-up beam consisting of two flange plates, welded to a web plate to form an **I**-section. The primary function of the top and bottom flange plates is to resist the axial compressive and tensile force caused by the applied bending moments. The main function of the web plate in a plate girder is to maintain the relative distance between the top and bottom flanges and to resist the applied 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 [6].

Web buckling due to shear is essentially a local buckling phenomenon. Depending upon the geometry, the web plate is capable of carrying additional loads considerably in excess of that at which the web starts to buckle, due to postbuckling strength. Taking advantage of this reserved strength, a plate girder of high strength per weight ratio can be designed.

Elastic buckling was used as a basis for the design of plate girder webs almost exclusively until the 1960s. This was due primarily to the fact that formulas for predicting the elastic shear buckling strength of web panels are relatively simple and had been known for many years. Indeed this partition of structural action is used as the basis for design in some Codes of Practice. For an economical design, it is advantageous to increase the distance between flanges. To keep the self-weight of the girder to a minimum the web thickness should be reduced as the depth increases, but this leads to web buckling considerations being more significant in plate girders than in rolled beams [7].

Shear buckling phenomenon becomes significant in webs with depth to thickness ratios greater than about 80. The actual shear strength of a web panel is dependent on yield stress, depth to thickness ratio of web, spacing of stiffeners and conditions of restraint provided by flanges. The web of a plate girder between stiffeners acts similarly to the diagonal of a truss. This phenomenon is known as tension field action.

The theory of plate girder states that a web will resist an applied load in three successively occurring stages i.e. stage 1, a pure shear field, stage 2, a diagonal tension membrane field, and stage 3, a collapse mechanism due to the formation of hinges in the flanges. In slender web panels, the limit of stage 1, i.e. the pure shear field, is reached when the applied shear stress reaches the elastic critical stress. Figure 1.3 illustrates the three stages of the collapse mechanism in the flat plate girder.

As mentioned above TWP beams and girders are designed to avoid the use of stiffeners along the web span. The same phenomenon is observed in TWP girders with regards to its slenderness ratio. The difference with the normal plate is that in the corrugated web, each flat field appears to be acting as a single simply supported flat plate [3]. In fulfilling the needs of design, modifications should be made to support the effect of the corrugation of the web regarding to its slenderness ratio, which is in the girder structure the slenderness ratio is up to 650.

1.4 Research Objectives

The primary objectives of this research are:

(a) To study the behaviour of trapezoidally corrugated web plate girder under shear force.

(b) To propose a formula for the critical shear buckling capacity of TWP section.

1.5 Scope of Study

The study involved experimental work and theoretical analysis. The scope of study is divided into several areas:

(a) Experimental study on the shear capacity of the corrugated web girders, which were provided by TWP Sdn. Bhd.

(b) Using a finite element application LUSAS to conduct a preliminary analysis and parametric study on several models with various configurations of the corrugation using Eigenvalue buckling analysis.

(c) Derivation of a formula for critical shear stress induced by a vertical shear force on the TWP model using the results of experimental tests and the analytical study of Eigenvalue buckling analysis.

Table 1.1 : Weight comparison on several fabricated steel section

	TWP Section	British Steel Section	IPE Section	Perwaja Section
Type	11	457x157x52	400	350x250x78.1
Moment Inertia (cm^4)	22.861	21.300	23.130	21.228
Weight (kg/m)	39	52	66	78

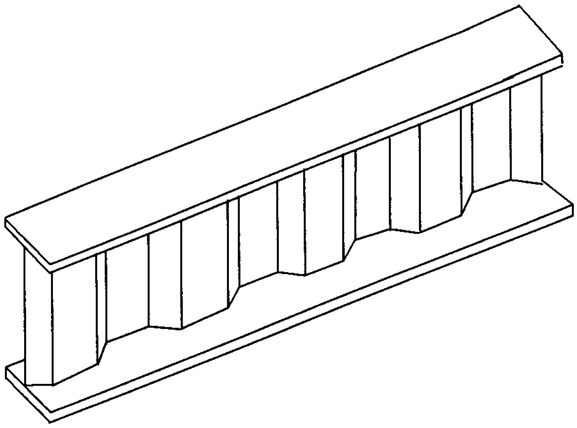
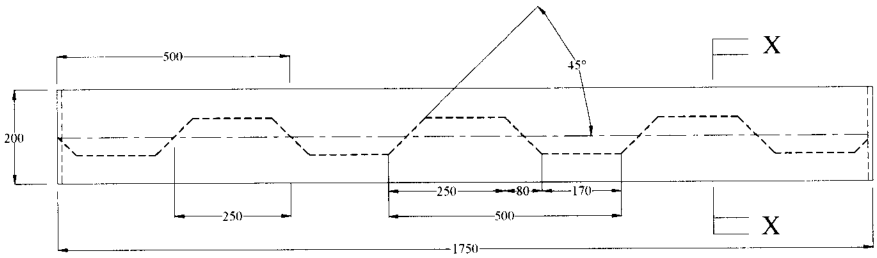
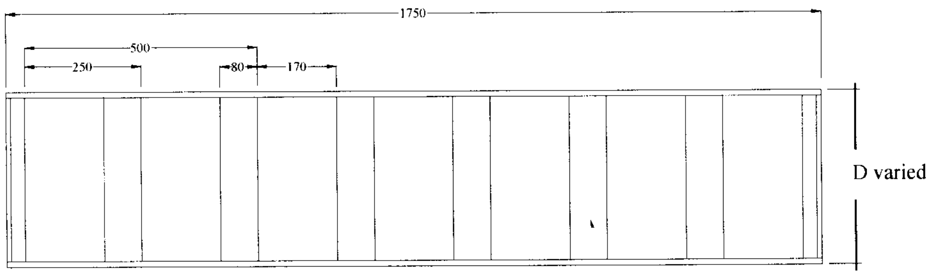


Figure 1.1 : Shape of TWP section

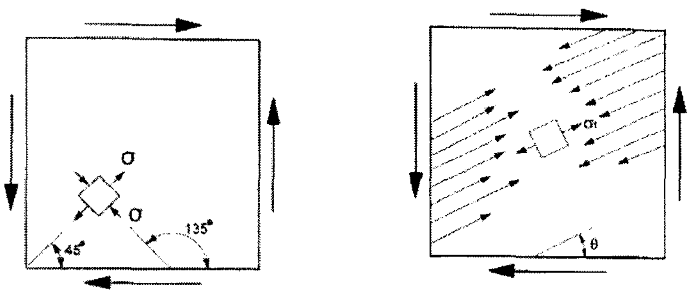


Plan view

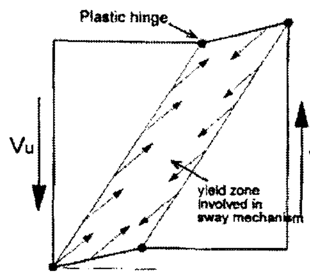


Side view

Figure 1.2 : Shape and dimension of TWP section



(a) Pure stress (b) Membrane action



(c) Formation of plastic hinge

Figure 1.3 : Stress distribution and collapse mechanism in the flat plate panel

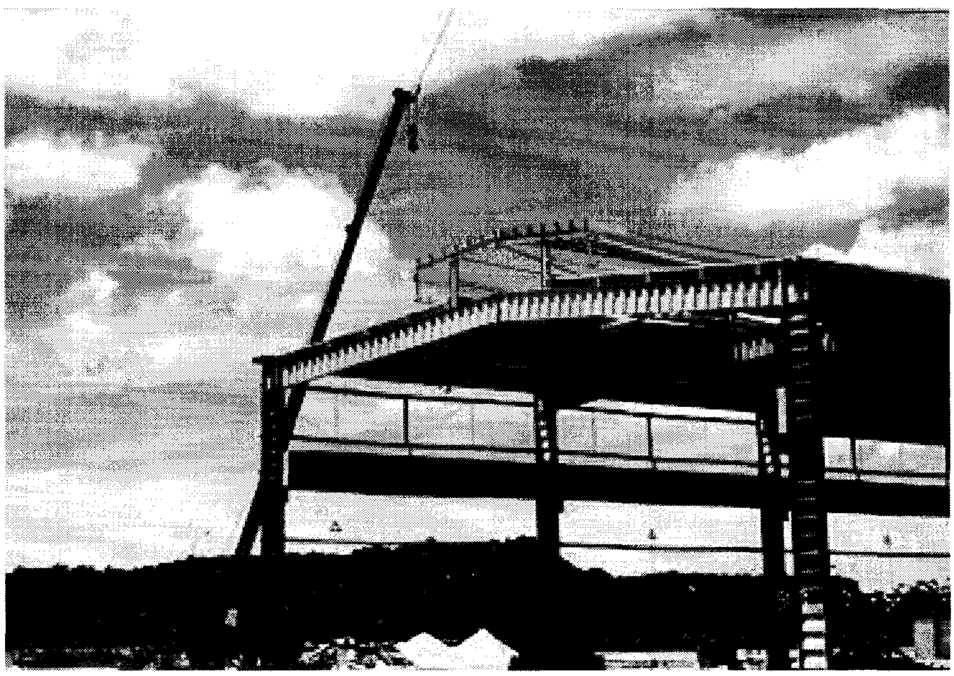


Figure 1.4 : Use of TWP beams in building construction

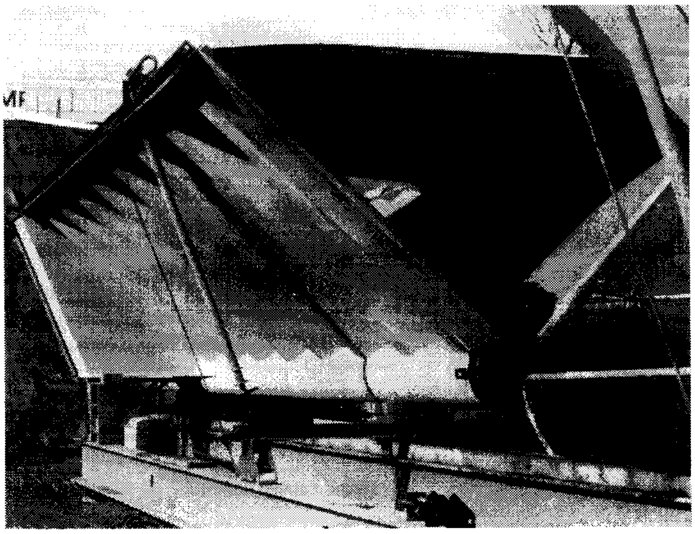


Figure 1.5 : Use of TWP beams in Maupre Viaduct Bridge, Charolless, France

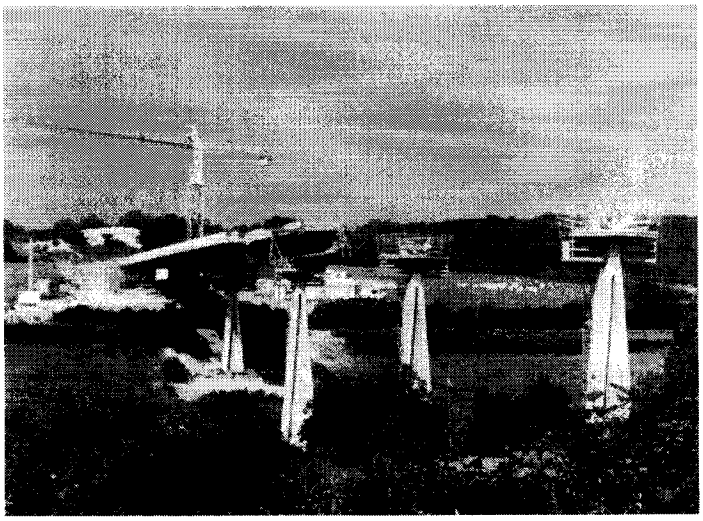


Figure 1.6 : The Maupre Viaduct Bridge, Charolless, France

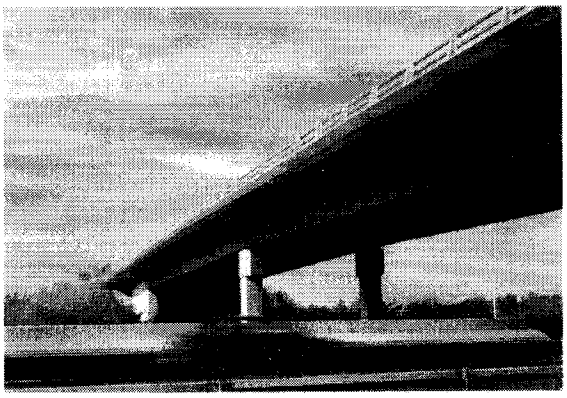


Figure 1.7 : Asterix Bridge , A1 Motorway Interchange, France

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Appendix A STRAINS AND STRESSES AT SPECIFIED LOAD DURING THE SHEAR TEST