UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL AND FINITE ELEMENT ANALYSES OF CORRUGATED WEB STEEL BEAMS SUBJECTED TO BENDING LOADS

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The behaviour of beams with corrugated web has been investigated throughout this study. They are commonly used in structural steel works to enhance the moment-carrying capability and weight reduction. Experimental tests and finite element analysis were conducted on beams with plane web (PW), horizontally corrugated (HC) and vertically corrugated (VC) webs.

Throughout the experimental tests, semicircular shape corrugation of 22.5 mm mean radius and 4.0 mm thickness was used. Two cases were considered for the HC beams, one arc (HC1) and two arcs (HC2) corrugation, while semicircular wholly corrugated was used for the VC type beams. All specimens were fabricated using tubes and flat plates of mild steel material (AISI 1020). The Instron testing machine was used for the three-point bending tests where three tests for each case have been carried out to obtain the load-displacement relations. The plane web I-section beams

with the mass per unit length value of 19.3 (kgm^{-1}) was also tested to act as the benchmark result.

In the analytical work, finite element models were generated and analysed by using LUSAS software. The material datasets were defined based on the actual stress-strain data obtained from the tensile tests. A series of elastic-plastic nonlinear analysis were carried out with the boundary settings similar to the experiment setup. Three corrugation radii of 22.50 mm, 33.75 mm and 67.50 mm were considered for the HC beams while five radii, in the range of 11.25 mm to 33.75 mm for the VC beams.

From the results obtained, the VC beams has yield loads of 60.621 kN to 73.308 kN or 13.3% to 32.8% higher than the welded plane web beams and 1.32-1.89 times and 1.56-3.26 times higher compared to the HC1 and HC2 beams respectively. The yield load increases as the larger size of radius was used, which is true for the sizes taken in this study. Moreover, as much as 13.6% of reduction in weight was achieved for the VC beams at the largest value of corrugation radius. A good agreement was found between the experimental and finite element analysis results where the percentage difference obtained was 7.28% to 28.37%.

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EKSPERIMEN DAN ANALISIS UNSUR TERHINGGA ALANG BESI BERALUN DIKENAKAN BEBAN MEMBENGKOK

By

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Kajian ke atas kelakuan alang beralun telah dijalankan. Ia biasanya digunakan untuk kerja-kerja melibatkan struktur besi dalam mempertingkatkan keupayaan menanggung beban momen dan mengurangkan berat struktur. Alang dengan bentuk rim tengah yang berbeza iaitu datar (PW), beralun melintang (HC) dan beralun menegak telah dikaji secara ujikaji dan analisis unsur terhingga.

Alunan berbentuk separuh bulatan dengan jejari min 22.5 mm dan tebal 4.0 mm digunakan dalam ujikaji. Bagi alang jenis HC, dua bentuk alunan dikaji iaitu satu lengkungan (HC1) dan dua lengkungan (HC2) dan alunan berbentuk separuh bulatan beralun menyeluruh bagi alang jenis VC. Semua spesimen dibikin dengan menggunakan bahan besi lembut (AISI 1020). Tiga ujian lenturan tiga-pin dijalankan ke atas setiap jenis alang dengan menggunakan mesin Instron untuk mendapatkan perkaitan di antara beban-sesaran. Alang biasa yang berbentuk I dengan rim tengah

yang rata juga diuji sebagai ujian kawalan. Berat semeter alang yang diuji ialah 19.3 kgm^{-1}.

Dalam kajian secara analitikal, model unsur terhingga dihasilkan dan diuji di bawah kesan lenturan tiga-pin dengan menggunakan perisian LUSAS. Sifat mekanikal bahan ditakrifkan daripada tegasan-terikan sebenar yang diperolehi dalam ujian ketegangan. Analisis-analisis tidak linear yang diprogramkan menyerupai keadaan dan susunan eksperimen telah dijalankan. Sebanyak tiga saiz jejari alunan digunakan bagi alang jenis HC iaitu 22.50 mm, 33.75 mm dan 67.50 mm, manakala lima saiz dalam lingkungan 11.25 mm hingga 33.75 mm bagi alang jenis VC.

Daripada keputusan yang diperolehi, alang jenis VC mempunyai nilai beban alah sebanyak 60.621kN hingga 73.308 kN atau 13.3% hingga 32.8% melebihi alang jenis PW yang dikimpal serta 1.32-1.89 dan 1.56-3.26 kali ganda nilai beban alah alang jenis HC1 dan HC2 masing-masing. Dengan menggunakan saiz jejari alunan yang besar, peningkatan dalam beban alah yang lebih ketara akan diperolehi. Tambahan pula, penurunan berat sebanyak 13.6% bagi alang jenis VC akan dicapai jika maksimum saiz jejari alunan digunakan. Perbandingan di antara keputusan eksperimen dan analisis unsur terhingga adalah memuaskan dengan peratus perbezaan yang diperolehi sebanyak 7.28% hingga 28.37%.

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LIST OF ABBREVIATIONS

A_{xy}	Area of cross section in the xy plane
A_{zx}	Area of cross section in the zx plane
b_f	Width of flange
d	Depth of beam
d_m	Mean diameter of corrugated web
ep	Effective plastic strain
e	Strain
E	Modulus of Elasticity
F	Load
F_U	Ultimate load
F_Y	Yield load
H	Corrugation amplitude
I_{xx}	Second moment of area with respect to x-axis
$I_{xx(EXP)}$	Second moment of area with respect to x-axis obtained from experimental tests
$I_{xx(FEA)}$	Second moment of area with respect to x-axis obtained from finite element analyses
$I_{xx(THEORY)}$	Second moment of area with respect to x-axis obtained from theoretical equations
L	Beam length/span
M	Bending moment
M_ω	Moment measured in sectorial coordinate-ω
M_Y	Yield moment
M_U	Ultimate moment
P	Load applied on compression flange
p	Loading position on vertically corrugated web beam
r	Corrugation radius
r_i	Inner radius/minor radius of arc
r_o	Outer radius/major radius of arc
S	Elastic section modulus
t	Web thickness at cross section
t_f	Flange thickness
t_w	Web thickness
V	Volume
W	Specific weight
w	Weight per unit length
ω	Sectorial coordinate
λ	Cycle length
σ	Direct stress
σ_{max}	Maximum bending stress
σ_U	Ultimate strength
σ_y	Yield stress
δ	Displacement
AISC	American Institute of Steel Construction
ASD	Allowable Stress Design
LRFD	Load and Resistance Factor Design

CHAPTER 1

INTRODUCTION

1.1 Types of Structural Beams

Structural beams are common building materials and normally made of steel. In order to simplify the design and construction process, all characteristics or geometries of the beams are specified in accordance to the approved standards such as the American Iron and Steel Institute (AISI), American Society for Testing and Materials (ASTM) and British Standards (BS). The common commercial structural shapes available are hot-rolled cross sections (such as wide-flange, channels and angles), pipe and hollow structural sections (HSS).

1.2 Ordinary I-Section Beams

The I-section beam or H-pile plays an important role in the construction industry for building of structures such as bridges, water tank supports and towers. Its uniqueness in shape, which consists of two parallel flanges and a slender web, creates more versatility to suit most working environments. It is commonly made from steel materials through hot or cold form-rolling process of steel bloom.

In line with the development of construction and manufacturing industries, higher requirement and quality standard sets for these beams is essential. Designers and manufacturers have used numerous ways in producing an ideal beam that is safer, reliable and economical in materials and production cost. These include modifying the ordinary shape of the beam and optimising the sizes to suit the demand. For instance, the hollow flange beam (HFB) was introduced in replacing the conventional beam type in certain application and usage of external or internal stiffeners to produce stronger structures.

However, these alternatives seem to be more expensive and added extra weight to the structure, making it impractical when delivery of materials is concerned. Some even appear to have contributed insignificant improvement to the beam's performance in comparison to the ordinary one.

1.3 Corrugated Web Beams

The beams with wholly corrugated web (WCW) has been introduced and used in building and construction industries. It could economise on materials and yet stronger in strength than the conventional beams. However, the information relevant to its mechanical behaviour and limitation in practice is inadequate. The effects of the corrugation parameters and beams' dimensions to the bending performance are still scarce.

Recently, as its application grew in many industries, especially construction, these parameters have been the main research subjects. The preliminary studies being carried out on such beams were mainly concentrated on the trapezoidal corrugation in the vertical direction. With reference to the available data from both experimental and analytical works, the corrugation has contributed equal stability to the web regardless of the materials thickness. This applies for the major loading modes like bending, shearing and buckling.

However, manufacturing of these beams is difficult and bounded by the limitation and tolerances of the process, which would limit its usage in practice. This is especially true when standardization of sizes is concerned.

1.4 Manufacturing Process of the Corrugated Web Beams

The general shape-rolling process adopted for the ordinary beams with flat web can not be implemented for the trapezoidal corrugated web type. At present, the web is welded continuously at the joints on the two flanges that produce an I-cross section. Nevertheless, strong joints could hardly be produced for beams with thinner web, even by the use of state of art welding technology that could possibly do the job. Higher cost will certainly be incurred that make it impractical especially for a longer span.

Thus, the curve wave-like corrugation was introduced to substitute the trapezoidal corrugation, as it seems more suitable to be manufactured. However, to date, the same welding method is being used in producing this corrugation shape where the hot rolled beam of the similar type has yet been produced by any manufacturer. Although, few successful in laboratory trials have been seen in some research works, but the design of the roll process and tools are not fully addressed. The design requirements of the roll tool for corrugated web beams are outlined as follow.