PLASTIC DESIGN OF BEAMS WITH REINFORCED RECTANGULAR WEB OPENINGS

by 632

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TABLE OF CONTENTS

INTRODUCTION

Problem:

In modern steel structures, openings are often provided in the webs of steel beams to provide for passage of utility components. In a multistory steel frame a considerable height differential is achieved by passing the utility components through web openings. This will considerably reduce the cost of the structure. Reinforcing may be required around the web openings depending on values of moment and shear at the opening. A designer needs a convenient method for determining when reinforcing is required and how much reinforcing is required.

Purpose:

The purpose of this report is to provide designers with a method for designing steel W-shape beams with reinforced rectangular openings in the webs.

Scope:

The method presented herein is based on an ultimate strength analysis and is applicable only to W-shape beams with:

1. Rectangular or square openings;
2. Openings centered on the longitudinal axis of the beams;
3. Reinforcing bars above and below the openings and parallel to the longitudinal axes of the beams as shown in Appendix A.

BRIEF SURVEY OF THE LITERATURE

A considerable amount of research has been directed toward determining the elastic stresses around openings in the webs of W-shape beams. Theoretical results were published by Muskhelishvili[8] in 1930, Heller[7] in 1962 and Bower[1] in 1966. An experimental analysis of circular openings was presented by So in 1963. Bower[2] also published the results of experimental investigations of rectangular and circular openings in 1966. An experimental elastic study was conducted at Kansas State University by Chang[4] in 1969.

An analytical study of the ultimate strength of beams with circular, rectangular and oval openings was reported by Redwood and McCutcheon[9] in 1968. Bower[3] summarized the results of another ultimate strength analysis in 1968. The plastic behavior and the ultimate strength design of beams with web openings were further discussed by Redwood in 1968.[10] All of these publications were restricted to web holes *without reinforcing*. Design charts for unreinforced web openings were prepared and published by U. S. Steel[12] in 1968.

A comparison of the economy of various reinforcing types was carried out by Segner.[11] Theoretical and experimental investigations on reinforced rectangular web openings were conducted by Cogdon[5] at McGill University and were published in 1969. Additional experimental work on the same problem has been reported by Cooper and Snell.[6]

SUMMARY OF DESIGN FORMULAS

Introduction:

(a) Interaction Diagrams: The plastic moment capacity of steel W-shape beams is effected by the presence of shear. The interaction diagram shown in Fig. 1a represents the effect of shear on the moment capacity of a beam and is based on Von Mises' yield criteria. The values of the applied shear V and applied moment M have been non-dimensionalised by dividing by M_p, the plastic moment, and V_p, the plastic shear force. The introduction of an opening in the web of a W-shape beam changes the interaction curve due to a change in the moment and shear capacity by the reduction of area available, and due to a stronger interaction between moment and shear. Figure 1b represents an interaction diagram for a beam with a web opening. This report presents interaction diagrams for the following three conditions:

(1) Unreinforced opening

(2) Opening reinforced to reach maximum shear capacity

(3) Opening reinforced for a further increase in moment capacity beyond that associated with the maximum shear capacity.

Beams with the following properties are considered for the above conditions:

(1) A_f/A_w = 0.5, 1.0 and 1.5; h/a = 0.5

(2) A_f/A_w = 0.5, 1.0 and 1.5; h/a = 1.0

where

A_f = area of one flange

A_w = area of web

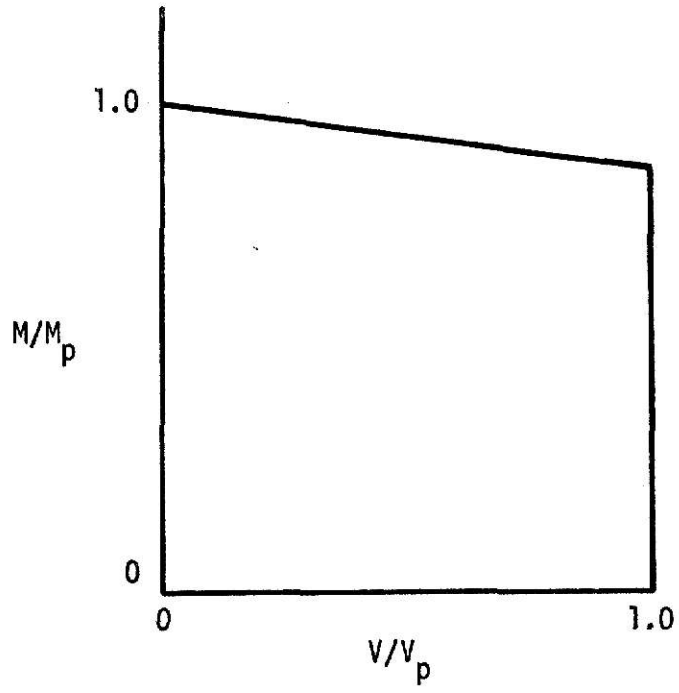

Fig. 1a. Interaction Diagram for a Beam Without an Opening

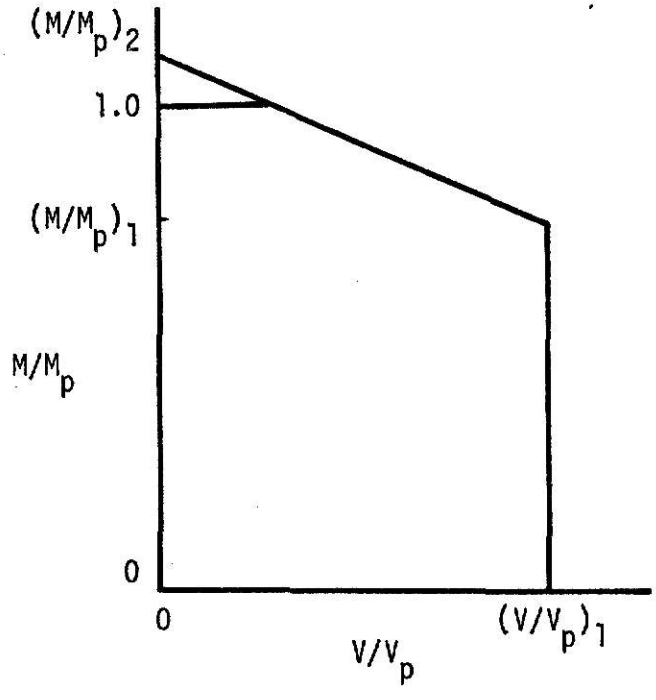

Fig. 1b. Interaction Diagram for a Beam With an Opening