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C. K. Chuang

T. Huang

J. H. Daniels

B. T. Yen

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Comparison of Haunched and Constant-Depth Steel Box Bridge Girders

T. Huang
C. K. Chuang
J. H. Daniels
B. T. Yen

Lehigh University
Bethlehem, Pennsylvania

ABSTRACT

For multispan highway and railroad bridges, haunched continuous steel box girders are often used as main load-carrying members. The use of haunches at the interior supports provides a variation of negative moment strength similar to that of the design requirements, therefore enhancing the structural efficiency of the design. The economy of a haunched profile is affected by a large number of parameters, including the span length, the span ratio, the midspan depth, the shape and size of haunches, and the configuration and thickness of the flanges. All of these must be considered to achieve the proper design regarding the adoption and geometry of the haunches.

This paper presents the results of a parametric study in which the costs of haunched and constant-depth continuous steel box girders are compared. Wide ranges of the parameters listed in the preceeding paragraph are included. The relative cost comparison is made based on equal stresses in the bottom flange of the box girder. Practical guidelines are developed for the selection of the haunched profile.

It is hoped that the results in this paper will provide some useful preliminary information for bridge engineers.

Introduction

In the last thirty years, the use of continuous thin-walled steel box girders as the principal load carrying members for bridge superstructures has gained considerable popularity. Haunches are often used to accommodate the large negative bending moments over the interior supports. The use of haunches not only yields a structurally efficient design, but also results in an aesthetically pleasing profile. However, because haunches also require more complicated fabrication procedures and possibly higher fabrication costs, they should not be used indiscriminately.

Many factors influence the performance and economy of a continuous steel box girder. The more significant factors include the span length, span ratio, depth of the structure at midspan, shape and size of haunches, and thickness of the web and flange plates. In this study, a well designed continuous steel box girder highway bridge, designated herein as the benchmark design is used as the basis for the examination of the effect of each of these design parameters.

The major cost items in a long span continuous steel box girder bridge such as the one studied herein are the material, fabrication and erection costs. The material costs for a particular superstructure at a given bridge location are essentially a function of the weight of steel including cross-frames, stiffeners, etc. The fabrication costs, although often expressed as a function of the total steel weight,are quite variable and are mainly related to the labor costs involved in the fabrication. These costs are, of course, larger for a more complex design which requires more cutting, fitting, welding, positioning, handling, etc. The erection costs are related to the type of erection scheme selected. For the ranges of parameters studied herein, the erection schemes could be essentially the same. Thus, the qualitative cost comparisons discussed in the paper reflect the relative costs of material and fabrication alone.

"Benchmark" Design

The structure analyzed is a twin haunched box girder bridge continuous over three spans, with span lengths of 375 ft., 590 ft., and 375 ft., respectively as shown in Figs. 1 and 2. Its out-to-out width is 106 ft., with 50 ft. curb-to-curb widths between the median barrier and each parapet. Each of the two box girders is 20 ft. wide, and 12 ft. 6 in. deep at midspan as well as the ends, with 27 ft. depth at the haunches. Haunches are parabolic in shape, and extend over 31.25% of the central span, and 61.5% of the side spans. The top flange consists of an orthotropic steel plate deck, with a 3 in. non-structural epoxy asphalt concrete pavement wearing surface. The bottom flange plates are stiffened longitudinally and vary in thickness from 7/8 in to 2 in. The thickness of web plates varies from 5/8 in. to 1 in. The bridge is designed for the standard HS20 highway loading (1), carrying three lanes of traffic in each direction. The steel has a nominal yield stress of 50 ksi.

Parametric Study

Each of the parameters enumerated earlier were modified to generate alternate design to be compared with the "benchmark" condition. Only one parameter was changed at a time. For each change in a parameter, the resulting box girder was analyzed for a wide range of haunch depths. Comparison of the results with those from the benchmark design provided insight into possible alternate designs incorporating the selected changes. The analyses were based on the Allowable Stress Method of the AASHTO Specifications (1). The controlling stresses were assumed to be those in the bottom flange plate at midspan, and at the interior supports.

The haunch depths were expressed in terms of a haunch ratio, HR, which was defined as the ratio of the maximum depth at the interior support to the minimum depth at midspan. The benchmark design has a haunch ratio of 27/12.5, or 2.16. In this study, the haunch ratio was varied from 1.0 to 3.0. A haunch ratio of 1.0 represents a constant depth girder. However, it should be emphasized that this does not necessarily indicate a uniform cross-section (or prismatic configuration). Variation of web plate and/or flange plate thicknesses will cause the moment of inertia of the cross-section to vary along the span, resulting in a non-prismatic, constant depth design.

The parameters examined in this study include the following:

1. Depth at midspan - DC
2. Thickness of the bottom flange plate - TB
3. Thickness of web plate - TW
4. Span ratio - SR

In addition, the "benchmark" design was also analyzed for a range of span lengths. It is recognized that the span length of a bridge structure may be restricted by non-structural considerations, such as navigation clearance. Nevertheless, it is included in this study in order to provide some assistance in the selection of a superstructure profile. The results of these analyses are presented in Figures 3 through 7. In each figure, the solid lines show the compressive stress in the bottom flange at the interior support. The dash lines show the tensile stress in the bottom flange at midspan, and the solid dots show the corresponding stresses in the "benchmark" design. In each case, only one of the parameters was altered, with all other parameters remaining the same as the benchmark design. The arrangement and configuration of the top flange, and the arrangement of stiffeners for the web and bottom plates were kept constant throughout these analyses. Although the actual arrangement of stiffeners would likely change for each of the different designs, it was assumed that the effect on the resulting cost comparisons would be negligible. Table 1 summarizes the range of each of the factors studied.

Effect of Haunch Ratio, HR

The effect of changing haunch depths is shown in Figure 3 through 7. It is clearly seen from these figures that, regardless of the design of the box cross-section, an increase in the haunch ratio would always decrease the stresses in the bottom flange at both the interior supports and the midspan section. For a given flange and web thickness, an increase of haunch depth is accompanied by an increase of section modulus at the haunch, an increase of the negative bending moment at the supports, and a decrease of the positive bending moment at midspan. The net result is reduced flange stresses at both places.

For the benchmark design, the tensile stress at midspan was calculated to be 29 ksi and the compressive stress at the interior supports was 21.8 ksi. These values corresponded to 0.58 and 0.44, respectively, of the nominal yeild stress. These values were used as benchmark stresses for comparison of the subsequent designs.

Effect of Midspan Depth, DC

The series of curves in Fig. 3 show the effect of the midspan depth, DC, on the stresses in the bottom flange of the continuous box girder. With all other design parameters held constant, an increase of midspan depth results in a decrease of flange stresses at both locations, and vice versa.

Judging by the calculated stresses shown in Fig. 3, it would be possible to change the haunch ratio without exceeding the benchmark stresses by adjusting the midspan depth. For example, increasing the midspan depth to 15 ft. would allow a reduction of the haunch ratio to 1.8. A further increase of the midspan depth to 17.5 ft. would permit a still lower haunch ratio of 1.5. In contrast, it is also possible to reduce the midspan depth to, say, 10 ft., with an increase of the haunch ratio to slightly larger than 3.0. However, it is not possible to adopt a constant depth profile within the examined range of midspan depth.

In Table 2 are listed several feasible alternate designs based on this series of analysis, and the caluclated superstructure weight, in comparison with the "benchmark" design. It should be emphasized that the weight comparison is not directly correlated to the cost comparison, since the total cost (material and fabrication) per pound of steel will depend, to a considerable extent, on the complexity of the details. It is possible that a lower total cost may be achieved with a structure with smaller haunches, even though weighing more. This effect on cost will be particularly strong if the haunches could be completely eliminated.

Effect of Bottom Flange Thickness, TB

Figure 4 shows the stress magnitudes for a series of designs which have bottom flange of uniform thickness throughout the three continuous spans. The stresses in the benchmark design, with flange thickness varying from 7/8 in. to 2 in., are also presented in the figure for comparison. Clearly, the use of thicker bottom flange plates results in lower stresses. Consequently, a reduced haunch ratio can be achieved. For example, using a uniform 3 in. bottom flange would permit a reduction of haunch ratio to approximately 1.7. As shown in Table 2, this alternate design weighs almost one-third more than the benchmark design. It is doubtful that any reduction in the fabrication cost would be able to compensate such a large increase in material cost.

Effect of Web Plate Thickness, TW

Analyses were made for a series of designs,with uniform web thickness throughout the entire structure, but with flange plates identical to the benchmark case. The resulting bottom flange stresses are depicted in Fig. 5. For all the different uniform web thicknesses from 1/2 in to 1 in., only slight changes occurred in either the tension stress at midspan or the compressive stress at interior supports.

The change of web plate thickness affects the section modulus of the box girders very little, thus changing the flange stresses very little. The change of total weight among these designs is also minor. However, thicker web plates would require less transverse stiffeners, and would probably result in a lower cost.

Effect of Span Ratio, SR

In Figure 6, the stresses in the bottom flange of the continuous box girder are examined for a variation of the span ratio, which is defined as the ratio of the side span length to that of the central span. The range of span ratios examined was from approximately 0.51 to 0.68 while the ratio for the "benchmark" design was 0.63. It is seen that a decrease in the span ratio results in an increase of the tensile stress at midspan, and a smaller decrease of compression stress at the interior supports, and vice versa. Therefore, in order not to exceed either of the "benchmark" stresses, any change in the span ratio would have to be accompanied by an increase in haunch ratio. However, it is noted that the effect of span ratio is much stronger on the tensile stress at midspan than on the compression stress at the interior supports. Consequently, alternate designs with smaller haunches may be possible with large span ratios if the bottom flange can be stiffened to allow higher stresses at the interior supports.

Effect of Span Length

The curves in Fig. 7 show the computed stresses in the bottom flanges of the box girders with different span lengths. For these cases, the arrangement of flange and web plates and the span ratio are kept the same as in the benchmark design.

By comparing with the bottom flange stresses of the benchmark design, it is noted that shallower haunches are sufficient for shorter spans. For a span length of 500 ft., a haunch ratio of 1.6 is sufficient. With spans less than 400 ft., constant depth box girders (HR=1.0) can be used. These comparisons demonstrate the significant relationship between span length and haunch ratio.

Examination of Table 2 shows that for shorter span lengths and shallower haunches, the weight of the structure becomes proportionally lighter. Considering further the possible reduction in unit fabrication cost, the economical advantage is evident. The analyses illustrated in Figure 7 were based on a midspan depth of 12.5 ft., the same as the benchmark design. It is felt that the feasible span range for constant depth profiles could be extended beyond 400 ft. if larger midspan depths are considered.

Figure 7 illustrates the sensitive relationship between haunch ratio and center span length. This information together with the effect of midspan depth in Fig. 3 provides qualitative guidelines for the selection of box girder profiles.

Summary and Conclusions

Examination of the results of the limited parametric study revealed several guidelines for the selection of the longitudinal profile of continuous steel box bridge girders. First and foremost, the advantage of haunches is less pronounced for short and medium span bridges. For the benchmark bridge cross-section, haunches are not economical for spans up to about 400 ft. For long spans, a haunched profile is necessary. In these cases, higher haunches result in lower flange stresses. Flange stresses are also reduced by an increase in midspan depth, but the effect is less pronounced than that of the haunch ratio. Thicker bottom flange plates would result in a reduction of stresses, but changes in web thickness have only a minor influence on flange stresses. Finally, for a fixed span length, an increase in the side span length would lead to reduced tensile stress at midspan, but a slightly increased compressive stress at interior supports.

This study was limited to altering only one design parameter at a time from the benchmark design. However, by considering several figures together, one can work towards the selection of an efficient and economical longitudinal profile of continuous box girders.

Acknowledgement

The topic of this study was inspired by a research project on the improvement of structural efficiency of the negative moment regions of continuous steel box girders, undertaken by the authors under the financial sponsorship of the Federal Highway Administration. Though not directly a part thereof, results of this parametric study is expected to be useful in the sponsored research.

References

1. American Association of State Highway and Transportation Officials
Standard Specifications for Highway Bridges, Twelfth Edition, 1977, with subsequent annual supplements.

TABLE 1

Range of Parameters

PARAMETER	RANGE	"BENCHMARK"
Haunch Ratio, HR	1.0 to 3.0	2.16
Midspan Depth, DC	10' to 17.5'	12.5'
Web Plate Thickness, TW	0.5" to 1"	Varies
Bottom Flange Thickness, TB	1" to 3"	Varies
Span Ratio, SR	0.51 to 0.68	0.63
Span Length	400' to 590'	590'

TABLE 2

Comparison of Alternate Design

Design	DC	TB	TW	SR	SPAN	HR	Weight of Steel (lb./sq. ft.)
Benchmark	12.5'	$\frac{7}{8}$∿2"	$\frac{5}{8}$∿1"	0.635	590'	2.16	93.65
DC Varied	17.5'	*(1)	*	*	*	1.5	98.79
	15'	*	*	*	*	1.8	96.34
	10.63'	*	*	*	*	3.	93.28
TB Varied	*	3"	*	*	*	1.7	125.50
	*	1.5"	*	*	*	2.7	100.83
TW Varied	*	*	0.5"	*	*	2.3	87.27
	*	*	1"	*	*	2.2	100.82
SR Varied	*	*	*	0.51	*	2.5	95.88
	*	*	*	0.68	*	2.2	94.16
SPAN Varied	*	*	*	*	400'	1	89.14
	*	*	*	*	500'	1.6	91.71

(1)*Signifies same value as in "Benchmark" design.

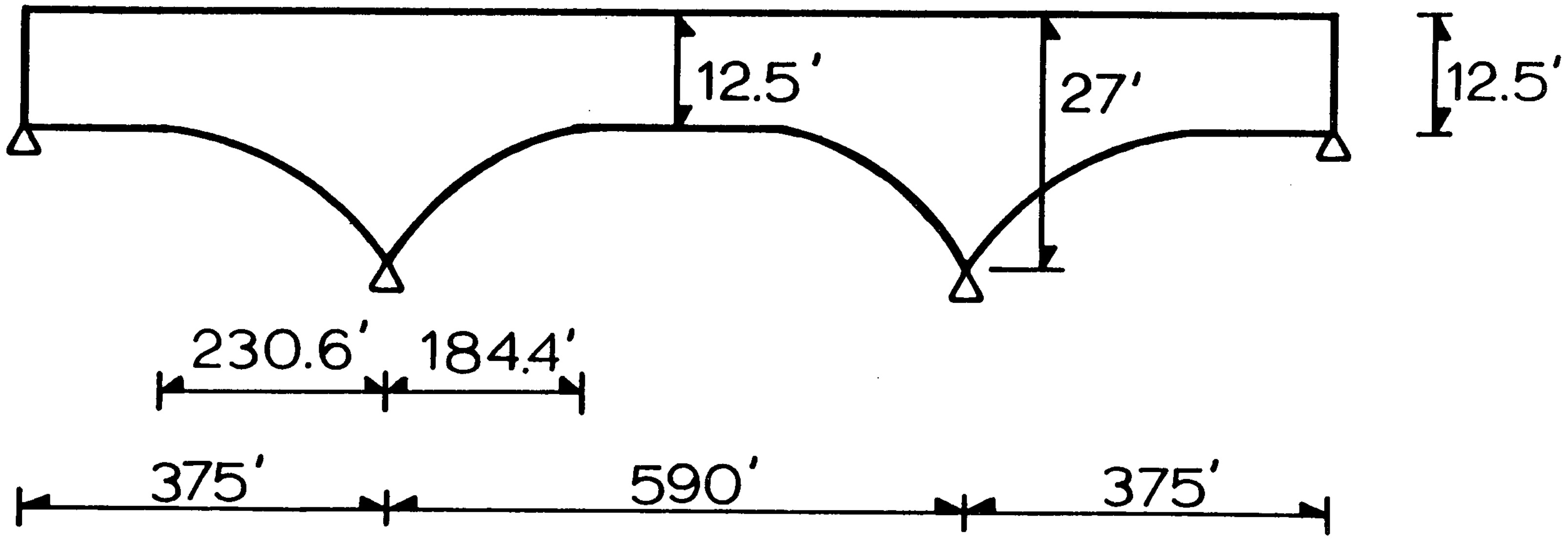

Fig. 1 - General Profile of Benchmark Bridge

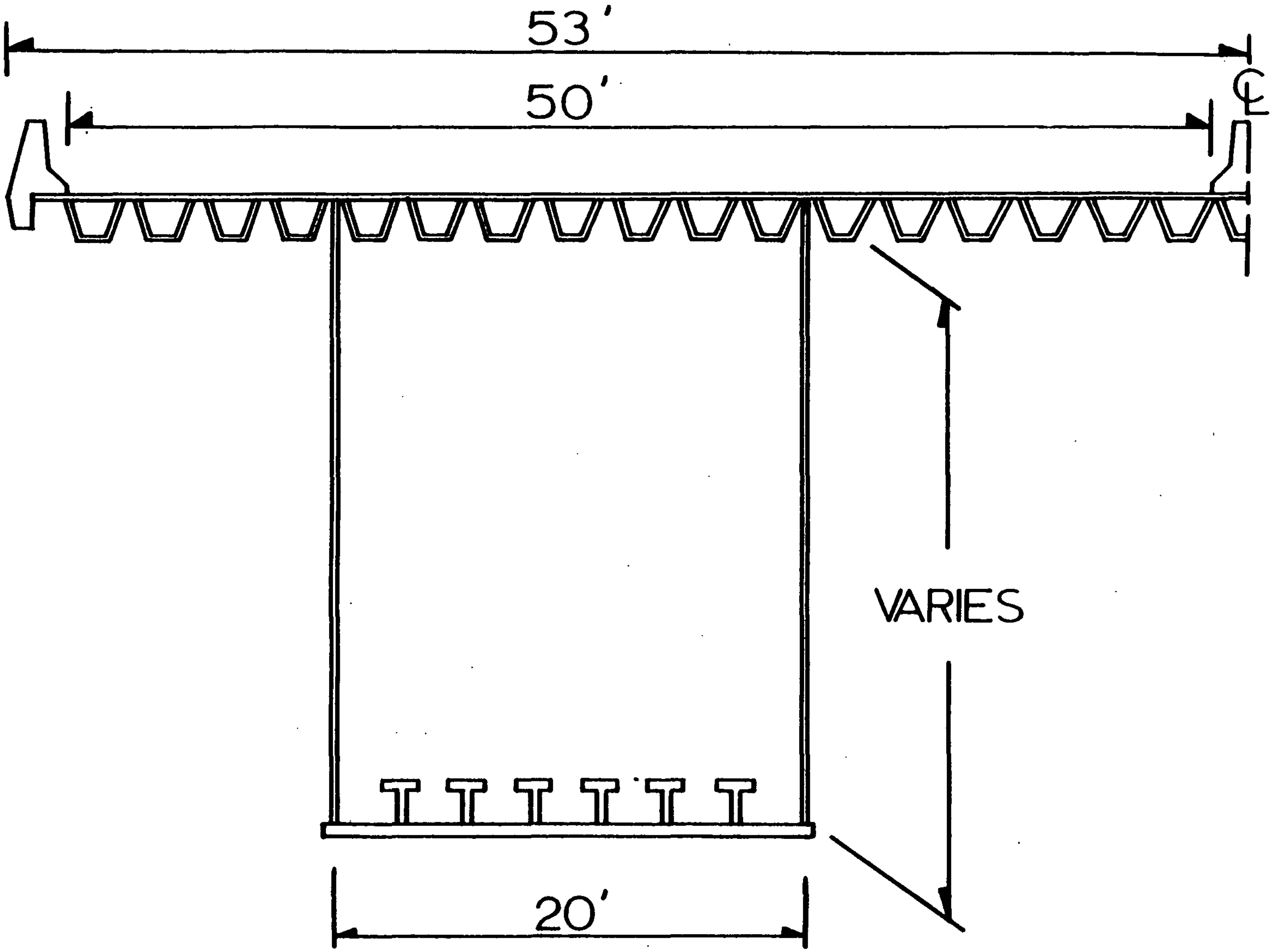

Fig. 2 - Typical Cross-Section

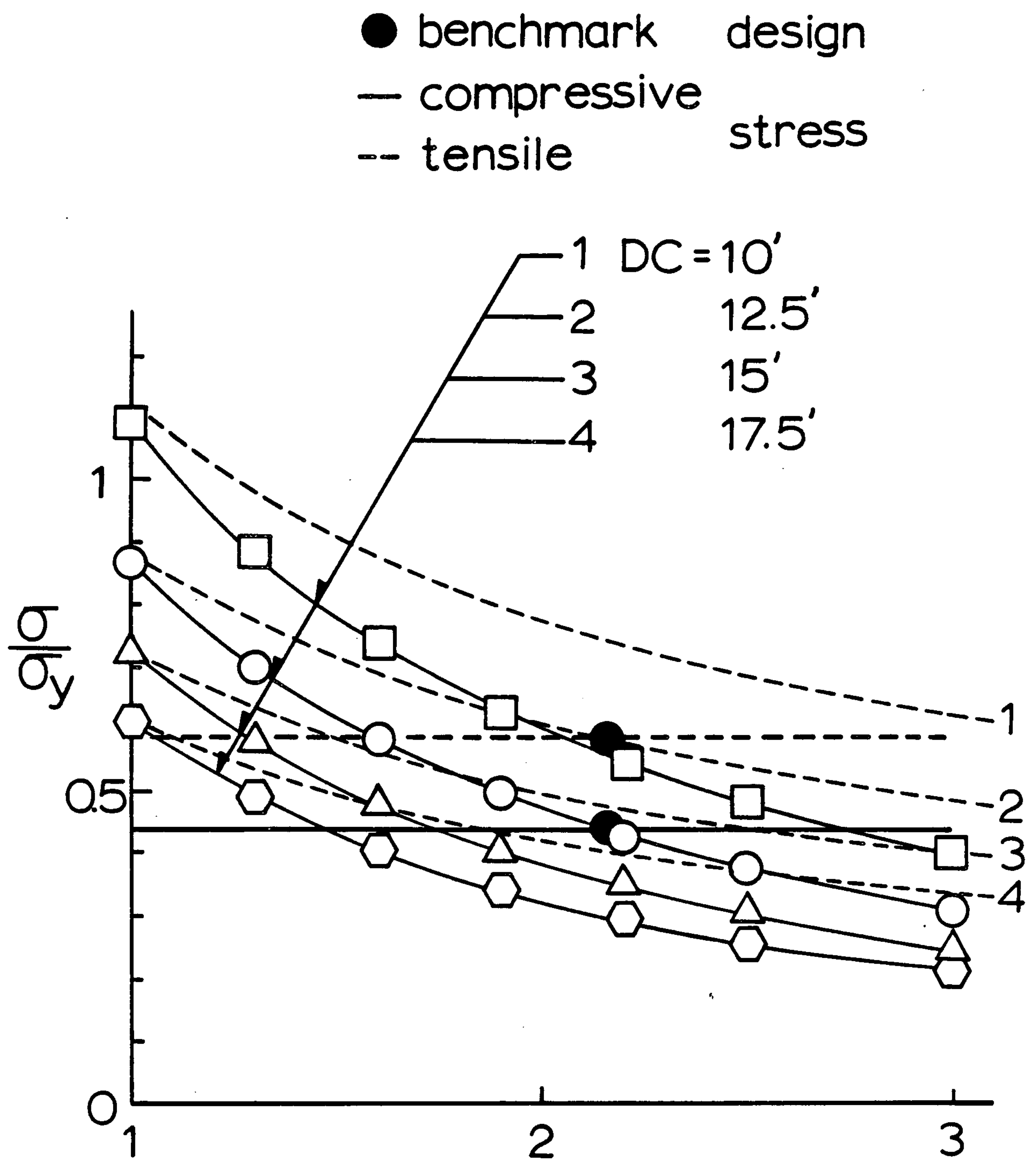

Fig. 3 - Effect of Midspan Depth

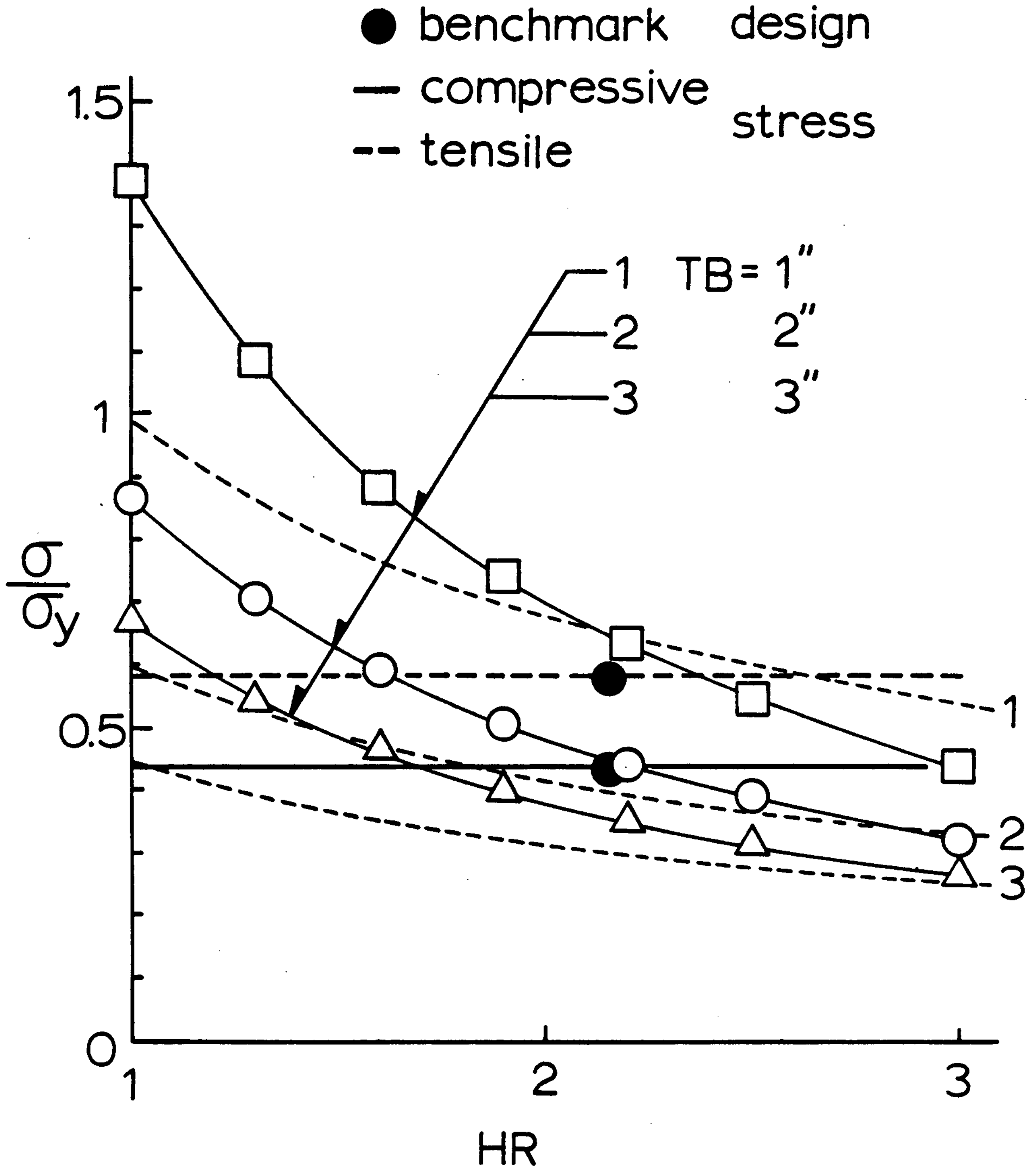

Fig. 4 - Effect of Bottom Flange Thickness

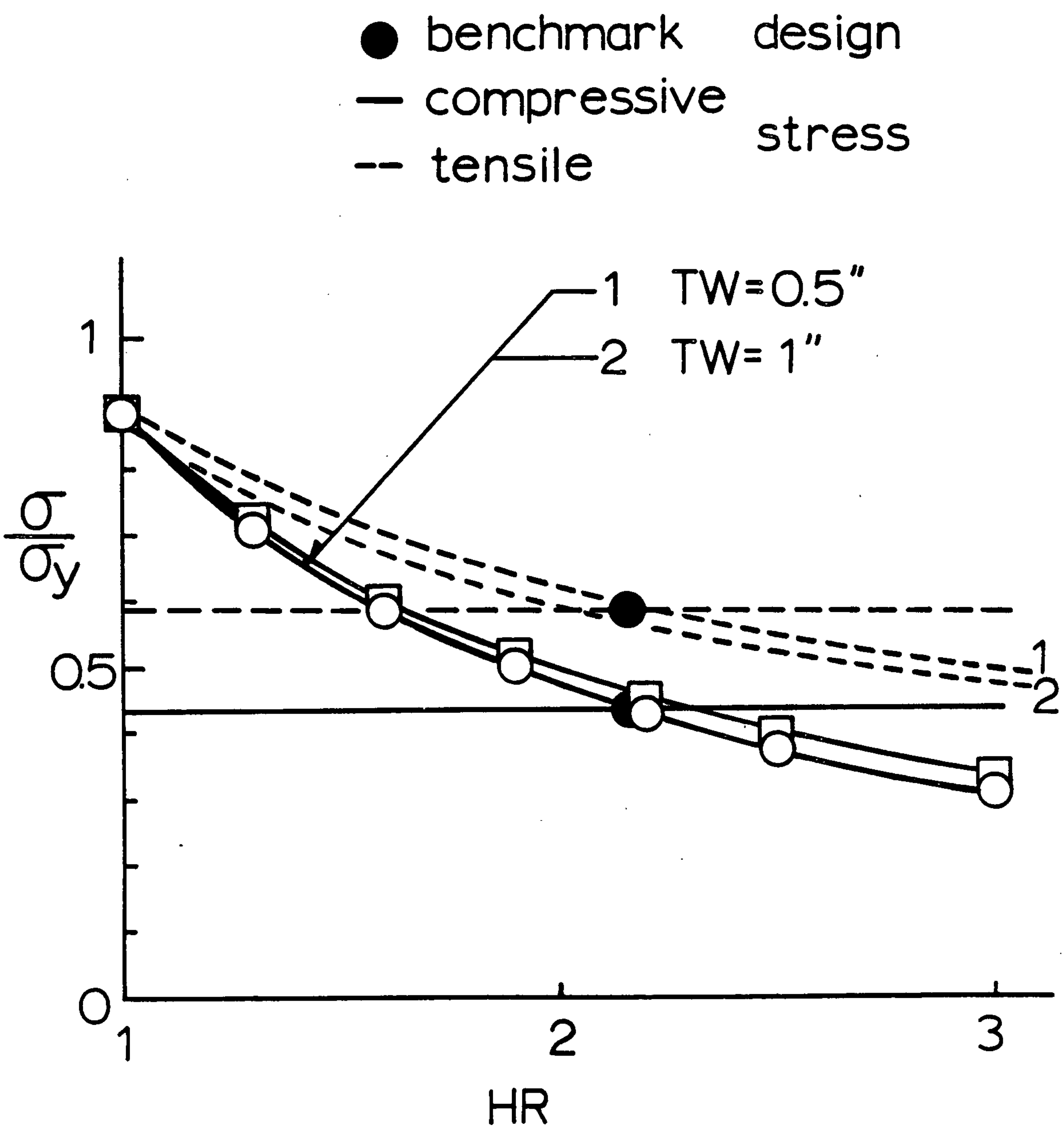

Fig. 5 - Effect of Thickness of Web Plates

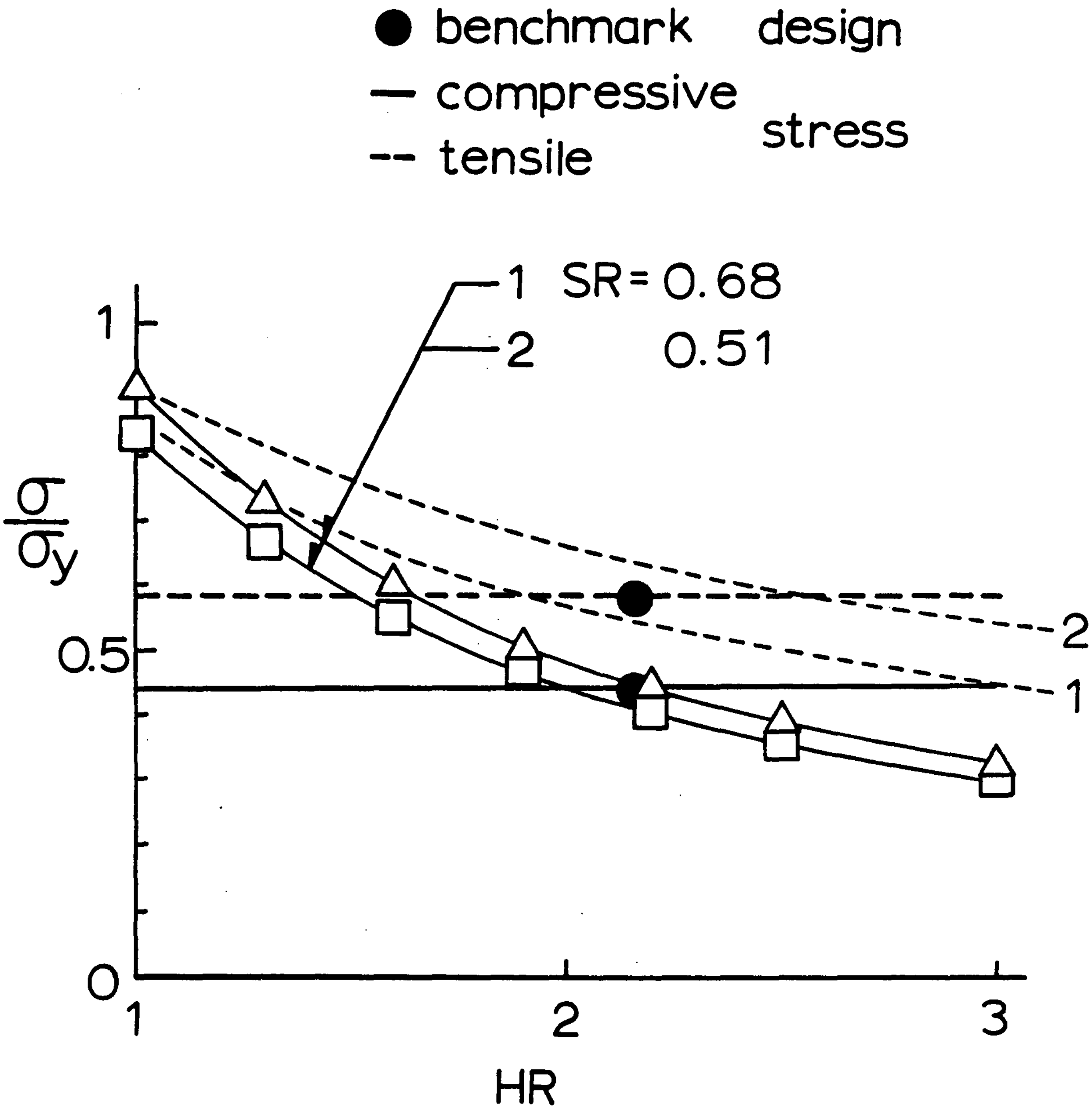

Fig. 6 - Effect of Span Ratio

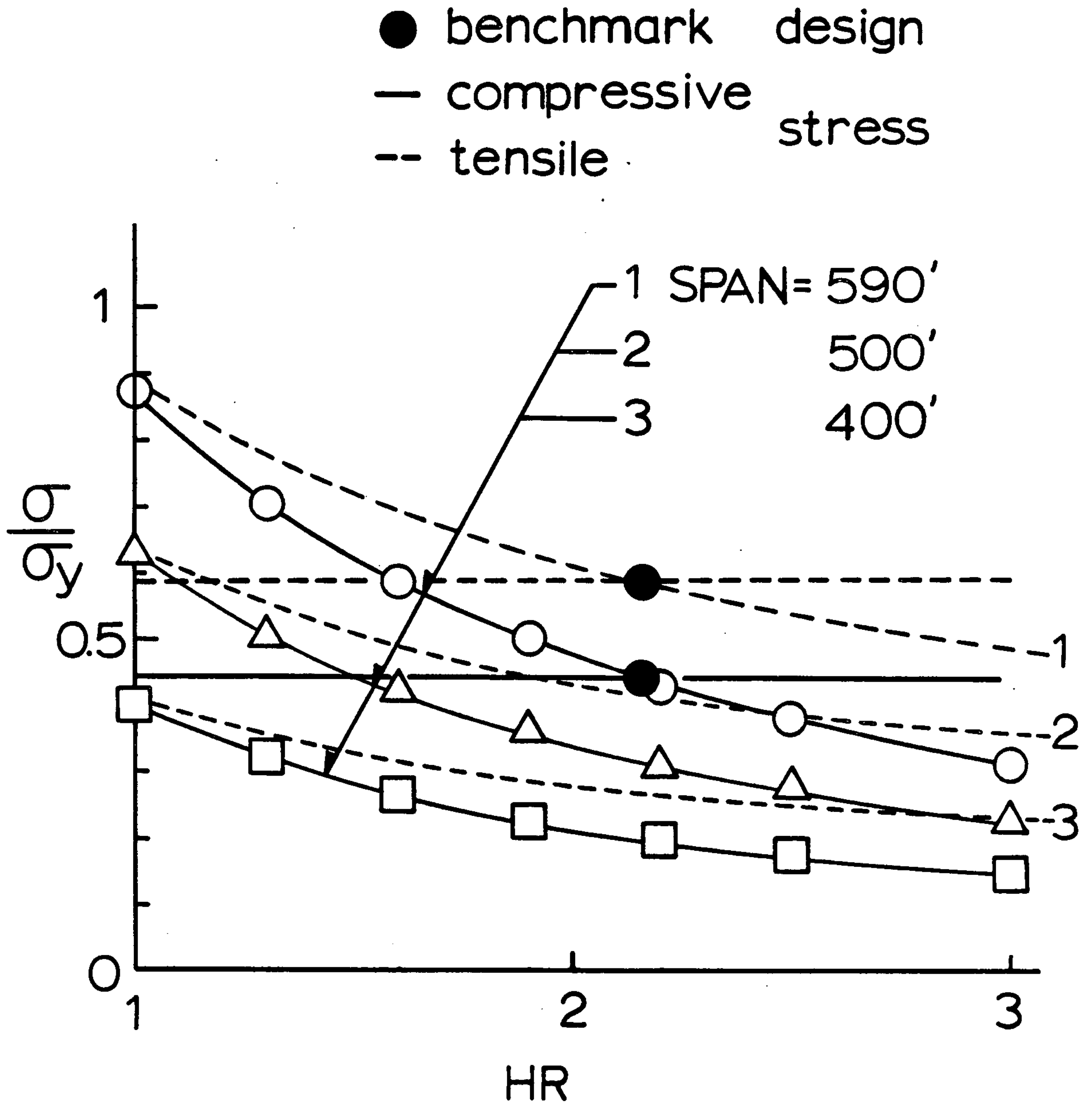

Fig. 7 - Effect of Span Length