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The effects of steel yield strength on the structural costs of stanchions

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Abstract

This work presents design studies on steel stanchions subjected to axial compression and bi-axial bending. The investigation centred on determining: the variation of cost of erecting a unit weight of steel stanchion with the grade of steel, depicted by the yield strength of the material; the effect of steel yield stress on the cost of short and slender columns and the possibility of introducing a new grade of steel (not provided for in the design code-BS449) that gives the optimum economy in stanchion design. The work also compared the cost of universal beam stanchion with that of universal column stanchion when both are selected for the same work. Results show that the yield stress for the most economical section varies depending mainly on whether the stanchion is slender or stocky. Also the use of universal beam section for stanchions should be restricted to stocky columns where strength rather than slenderness considerations govern the design.

Keywords: Steel stanchion; Yield stress; Relative weight; Relative cost; Slender column; Stocky column

1. Introduction

For use in building British steel designers have only three grades of structural steel to choose from. These are grades 43,50 and 55 with yield stresses of 250N/mm^2, 350N/mm^2 and 430N/mm^2 as per BS449 (1969) and grades S275, S350 and S460 with yield stresses of 275N/mm^2, 350N/mm^2 and 460N/mm^2 as per BS5950 (1986).

In the United States, Structural designers in steel have a wider range of grades of steel to choose from, AISC (1970) and this ultimately gives rise to more economical sections.

In an earlier reports the author examined the effects of steel yield strength on the structural cost of beams and plate girders and concluded that the results of the investigations do not favour the introduction of any new steel grades, Chidolue (2005).

For use in building the older but still quite popular permissible stress code BS449 (1969) has now been largely superseded by BS5950 (1986) which is a limit state code introduced in 1985. Under the new code structural steel is now manufactured in three basic grades; S275, S350, S460, where "S" stands for structural and the number following it indicates the yield strength of the material in N/mm^2.

This work involves design studies on structural members subjected to axial compression and bending stresses. Referred to by various terms such as column, stanchion, post and strut these members are rarely if ever actually carrying compression load alone. It is well known that only very short columns can be loaded to their yield stress. For slender columns the usual situation is that buckling, as a result of instability, occurs before the development of full material strength of the member. The theory of in-plane instability of columns and other compression members is extensively covered in many texts, Kirby et al. (1979), and is not considered in this report.

The investigation was confined to the use of universal column (UC) and universal beam (UB) sections since these are the sections most frequently used in buildings as stanchions. Special attention was given to the use of Safe load tables for selection of suitable sections for stanchions. Nevertheless since these tables are applicable to grades 43, 50 and 55 steel as per BS449 (1969), designs in proposed grades of steel were carried out using the permissible stress approach.

The effect of end moment and eccentricity of loading was examined by considering the case of a structural member subjected to combined bending and axial load. The coverage in this case was limited to available steel grades 43, 50 and 55 for which stanchion design charts, Brown (1971), are available. Although references were made to the new British Code of practice BS5950, designs were essentially carried out using BS449 provisions.

1.1. Grades of structural steel

Before the introduction of BS 5950 in 1985, all normal constructional steel work were carried out using steel manufactured in accordance with BS 4360 (1972) This standard gives several basic strength grades for steel of which the following three are normally available and are known as grade 43, grade 50 and grade 55. These figures indicate minimum ultimate tensile strength of 430, 500 and 550N/mm^2 respectively. Each strength grade has several sub-grades indicated by a letter between A and E.

Following the introduction of new British code of practice BS5950 structural steel grades available in UK are S275, S350, and S460. Thus, BS449 classification was based on the ultimate tensile strength of steel while BS5950 classification was based on yield strength of steel.

In Australia, AS1250 (1981), the number of grades of steel available was limited to three. These are grades 200, 250, and 350. The grade designation being a number which is the minimum yield stress in N/mm^2 rounded to the nearest multiple of 50.

1.2. Costs of structural steel

The cost of any structural steel work is made up of the basic price for steel and the fabrication cost. The basic price of rolled steel sections is made up of the basis price (which is the price of a grade 43 UB or UC section, table 1) plus the quality extra price, table 2.

Fabrication cost varies considerably from town to town and from nation to nation depending on the cost of labour. Information obtained from the marketing manager, British Steel Corporation (the research was initiated in Britain), indicate figures varying from £41,250.00 per tonne for single beam and column work to £70,000.00 per tonne for portal frames.

2. Methodology

This study was aimed at:

(a) Determining the variation of cost of erecting a unit weight of steel stanchion with the grade of steel, depicted by the yield strength of the material.
(b) Determining the effect of steel yield stress on the cost of short columns and slender columns.
(c) Comparing the cost of UB stanchion with UC stanchion when both are used for the same work; short (stocky) column or long (slender) column.
(d) Determining a possible grade of steel (not provided for in BS449) that gives the optimum economy in stanchion design.

In order to achieve these objectives, numerical design problems were selected such that the effects of variation of yield stress on material cost of short columns and long columns (problems 1 and 2) are examined.

For designs in existing grades of steel safe load tables, BCSA (1971), were used to select UC and UB sections required to carry the loads. For designs in the proposed grades of steel for which safe load tables were not available, suitable sections were selected by carrying out normal column design calculations. The permissible stresses were obtained by interpolating from the permissible stresses of the existing grades. Thus, for a proposed grade of steel with yield strength falling between those of grade 43 and 50 we have:

$$\mathrm{P}_{ys} = P_{43} + [P_{50} - P_{43}]\frac{[Y_s - Y_{43}]}{[Y_{50} - Y_{43}]} \qquad (1)$$

Where p_{ys} = the allowable stress in bending or in shear for steel with yield stress y_s.

P_{43}, p_{50}, p_{55} are the allowable stresses in bending or in shear for grades 43,50, and 55 steel respectively, obtained from the relevant tables in the standard, BS449 (1969).

Y_{43}, y_{50}, y_{55} are the yield stresses of grades 43, 50, and 55 steel respectively.

For non-existing grades of steel with yield stress between those of grade 50 and 55 the equation for interpolation of permissible stresses is given by:

$$P_{ys} = P_{50} + (P_{55} - P_{50})\frac{[Y_s - Y_{50}]}{[Y_{55} - Y_{50}]} \qquad (2)$$

In order to study the variation of costs with yield strength for eccentrically loaded stanchion numerical problem number 3 was chosen and designs were accomplished using stanchion design charts. Here only the case of existing grades of steel was examined because of limitations in the use of stanchion design charts for non-available grades of steel.

The basis prices of rolled steel sections (Table 1) shows that steel is sold in pound (Naira) per tonne. This led to the adoption of minimum weight design in all the numerical problems considered. The total cost of steel section selected based on this principle was then

evaluated by applying the basis cost, the quality extra price and the fabrication cost.
In order to eliminate the effect of variation of costs of steel in time and place, the total cost of the selected section was converted to relative material cost based on the cost of grade 43 material for the same design. This means that the results obtained are independent of the currency used.
Thus, Relative Material Cost =

$$\frac{\text{cost of UC or UB stanchion with yield stress } Y_s}{\text{cost of UC stanchion of grade 43 material}}$$

Relative Weight of Material is similarly defined

Numerical design problems
Problem no. 1
A ground floor column of a multi-storey block with the following data;
Height of column = 3.00m
Concentric axial load at column base = 5,000KN
Effective length factor = 0.70
Effective length = 2.10m

Problem no. 2
A column 5m high, supporting 1250KN load in a single storey industrial shed.
Effective length factor = 0.70
Effective length = 3.50m

Problem no. 3
A corner stanchion in a multi storey office block with a constant storey height of 2.50m.
It is assumed that the beam reactions; 1000KN in x-direction, 500KN in y-direction, are applied at 100mm eccentricity from the face of the stanchion
Concentric axial load on column = 5000KN
Effective length of column = 2.5m
Total imposed load on stanchion = 6500KN

3. Results and discussion

The results of the design studies are shown in tables 3, 4, and 5, for problems 1, 2, and 3 respectively. Figures 1 and 2 show the variation of relative cost of material with yield strength for short (stocky) column and long (slender) column respectively. These results are examined and discussed in the following paragraphs.

3.1. Economic material strength for short columns

Figure 1 shows that increase in the quality of material used for stanchion serving as a short column has corresponding cost benefit, and at a material strength of 400N/mm^2 maximum economy was attained. This shows about 30% saving over the use of grade 43 material (250N/mm^2 yield strength).

3.2. Economic material strength for slender columns

Figure 2 indicates that optimum cost savings in slender column is obtained at material strength of 300N/mm^2. Beyond this point, the cost of material increases directly with increase in material strength. For UC stanchions the cost of proposed grade of steel with 300N/mm^2 strength is about 20% cheaper than the cost of grade 43 material (Y_s=250N/mm^2).
For UC section the cost differential is 15% in favour of 300N/mm^2 proposed steel grade.

3.3. Efficiency of sections

Figure 2 clearly shows that for slender columns, universal column (UC) sections are more economic in cost than universal beam (UB) sections. This is because of the higher efficiency of material disposition in UC sections.

It is clear that for pure axial compression the allowable stress pc on a cross section increases with decrease in slenderness ratio. Therefore for a given effective length of a stanchion the most efficient section is one whose material is disposed away relative to the minor axis so as to maximise the radius of gyration of the section. By disposing the material as far as possible away from the centroid of UC sections, higher radii of gyration and hence lower slenderness ratios are obtained. Consequently the permissible stresses are higher for UC sections, giving lighter and cheaper sections.
An exception to this rule is in the design of short columns where designs are controlled by strength rather than slenderness effects. Figure 3 shows that in such situation either UC or UB section may be used without any economic disadvantage.

3.4. Effect of eccentricity of loading

Table 5 shows that for eccentrically loaded short columns optimum economy is obtained using the highest strength material, ys = 450N/mm^2. This shows that the factors affecting the economic material strength of short stanchions are the same irrespective of whether the column is concentrically or eccentrically loaded. Since the eccentrically loaded column (problem no 3) falls into the class of short column, it would be expected that strength rather than slenderness effects control the design.

Optimum economy in weight and material cost was obtained at a yield stress of 430N/mm^2, which is close to yield stress of 400N/mm^2 obtained for problem no 1, short concentrically loaded column. Thus it can be concluded that load eccentricity has little or no effect on the material strength required for minimum cost design.

3.5. Limitations to the use of safe load tables and stanchion design charts

The handbook on Structural Steel Work, BCSA and Constrado (1971) contains safe load tables for stanchions designed in accordance to BS 449(1969). Safe loads were tabulated for compression members having slenderness ratio not exceeding the maximum value specified in clause 33 of BS449. For compression members subjected to eccentric loading the required sections could not be obtained using Safe Load tables, which were prepared for only concentrically loaded members. Therefore, for design of moment resisting stanchions other method of design such as the use of stanchion design charts had to be adopted.

Stanchion design charts are graphical representations of safe loads and moments for stanchions design to BS449. They are standard quick reference for the choice of stanchion sections. Because of the speed with which they enable a suitable section to be chosen, the charts were particularly useful in the consideration of several alternative designs. It covers the whole range of universal column sections listed in BS 4 part1 (0000) and certain universal beam sections commonly used as stanchions in steel to BS 4360, grades 43, 50 and 55.

4. Conclusions

From the results of the investigations it can be concluded that the optimum strength for most economical section varies depending mainly on whether the stanchion is slender or stocky.

For heavily loaded stocky columns substantial economy in weight and cost were secured at highest material strength i.e. grade 55 stanchions. For slender or long columns economy in weight and cost of material was obtained at much lower material yield strength depending on the slenderness of the column. Material yield strength of 300N/mm^2 was observed as the most economic strength for the long column considered. Even though the grade of steel with yield stress of 300N/mm^2 was not covered in either BS 449 (old code) or BS 5950 (new code), the introduction of a new grade of steel is not recommended until further investigations on the effect of variation of slenderness of stanchion on material cost is carried out. Finally, the use of universal beam [UB] sections for stanchions should be restricted to stocky columns where strength rather than slenderness considerations govern the design.

Generally, in columns and compression member design the higher strength steels can be used to advantage if the slenderness ratio, l/r, is small (below 60). In addition when steel dead load is a major portion of the design load, higher strength steels can also be used to advantage.

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Table 1
Grades of structural steel

Code	*Grade*	*Yield strength n/mm^2*
BS 449	43	250
(1969)	50	350
	55	430
BS 5950	S275	275

(1986)	S350	350
	S460	460
AS 1250	200	200
(1981)	250	250
	350	350
Proposed Grades / Strength For This Work (BS 449)		275, 300, 325 375, 400, 425

Table 2
Basis prices of rolled Uc and Ub sections (Bsc 1983)

UNIVERSAL COLUMN SECTIONS				*UNIVERSAL BEAM SECTIONS*			
SIZE (mm)		WEIGHT (Kg/metre)	PRICE £/Tonne	SIZE (mm)		WEIGHT (Kg/mm)	PRICE £/Tonne
356 x 406	x	634	315.00	406 x 178	x	74	270.00
356 x 406	x	551	315.00	406 x 178	x	67	270.00
356 x 406	x	467	315.00	406 x 178	x	60	260.00
356 x 406	x	393	315.00	406 x 178	x	54	245.00
356 x 406	x	340	310.00	406 x 406	x	46	270.00
356 x 406	x	287	310.00	406 x 406	x	39	270.00
356 x 406	x	235	310.00	356 x 171	x	67	270.00
356 x 368	x	202	310.00	356 x 171	x	57	270.00
356 x 368	x	177	310.00	356 x 171	x	51	255.00
356 x 368	x	153	305.00	356 x 171	x	45	255.00
356 x 368	x	129	305.00	356 x 127	x	39	275.00
305 x 305	x	283	290.00	356 x 127	x	33	275.00
305 x 305	x	240	285.00	305 x 165	x	54	265.00
305 x 305	x	198	285.00	305 x 165	x	46	265.00
305 x 305	x	158	285.00	305 x 165	x	40	240.00
305 x 305	x	137	285.00	305 x 127	x	48	270.00
305 x 305	x	118	285.00	305 x 127	x	42	270.00
305 x 305	x	97	280.00	305 x 127	x	37	260.00
254 x 254	x	167	285.00	305 x 102	x	33	280.00
254 x 254	x	132	280.00	305 x 102	x	28	270.00
254 x 254	x	107	270.00	305 x 102	x	25	270.00
254 x 254	x	89	260.00	254 x 146	x	43	255.00
254 x 254	x	73	250.00	254 x 146	x	37	255.00
203 x 203	x	86	270.00	254 x 146	x	31	240.00
203 x 203	x	71	270.00	254 x 102	x	28	280.00
203 x 203	x	60	260.00	254 x 102	x	25	275.00
203 x 203	x	52	255.00	254 x 102	x	22	270.00
203 x 203	x	46	240.00	203 x 133	x	30	255.00
152 x 152	x	37	250.00	203 x 133	x	25	240.00
152 x 152	x	30	250.00				
152 x 152	x	23	240.00				

Table 3
Quality extra price (£/ tonne)

Not Impact Tested Grade		*Impact tested Grade*			
42A	43B	43B	43C	43D	43E
Basic Price	+£6.00	+£8.00	+£8.00	+£14.00	+£44.00
	50B		50C	50D	
	+£24.00		+£30.00	+£50.00	
			55C		
			+£50.00		

Table 4
Results for short column design
(a) Universal column as stanchion

Yield stress N/mm²	*Weight Of Section Kg/m*	*Basic Cost £*	*Total Cost £*	*Relative Weight %*	*Relative Material Cost %*
250	283	271	411	100	100
275	283	276	416	100	100
300	235	249	365	83	89
325	235	253	369	83	90
350	198	200	298	70	73
375	198	205	303	79	74
400	177	202	290	63	71
430	177	208	295	63	72

(b) Universal beam as stanchion

Yield Stress N/mm²	*Weight of Section Kg/m*	*Basic Cost £*	*Total Cost £*	*Relative Weight %*	*Relative Material Cost %*
250	289	296	439	102	107
275	253	263	389	89	95
300	238	244	362	84	88
325	224	241	352	79	86
350	201	217	316	71	77
375	194	214	310	69	75
400	176	198	285	62	69
430	170	199	284	60	69

Table 5
Results for slender column design
(a) Universal column as stanchion

Yield Stress N/mm²	*Weight of Section Kg/m*	*Basic Cost £*	*Total Cost £*	*Relative Weight %*	*Relative Material Cost %*
250	86	128	199	100	100
275	86	130	201	100	101
300	71	110	168	83	84
325	71	112	170	83	85
350	71	117	175	83	88
375	71	117	175	83	88
400	71	120	178	83	89
430	71	123	182	83	91

(b) Universal beam as stanchion

Yield Stress N/mm²	*Weight of Section Kg/m*	*Basic Cost £*	*Total Cost £*	*Relative Weight %*	*Relative Material Cost %*
250	101	156	239	117	120
275	89	130	203	103	102
300	82	127	194	95	97
325	82	129	197	95	100
350	82	132	199	95	100
375	82	135	203	95	102
400	82	138	206	95	104
430	82	143	210	95	106

Table 6
Results for eccentrically loaded short column:
Universal column as stanchion

Yield Stress N/mm²	*Weight of Section Kg/m*	*Basic Cost £*	*Total Cost £*	*Relative Weight %*	*Relative Material Cost %*
250	551	477	705	100	100
350	393	364	526	71	75
430	340	332	473	62	67

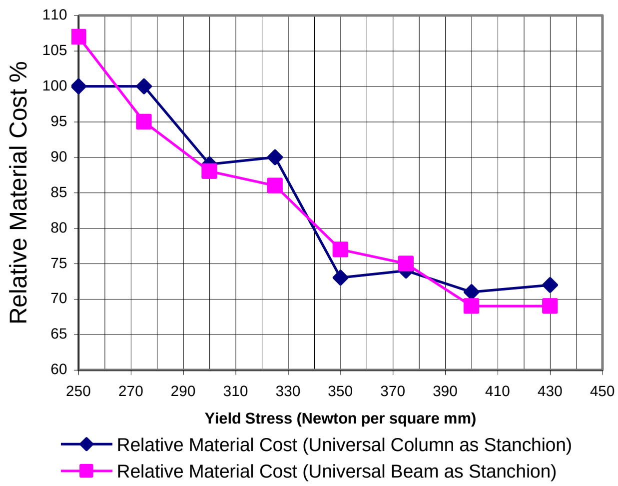

Fig.1. Variation of yield stress with material cost of short column.

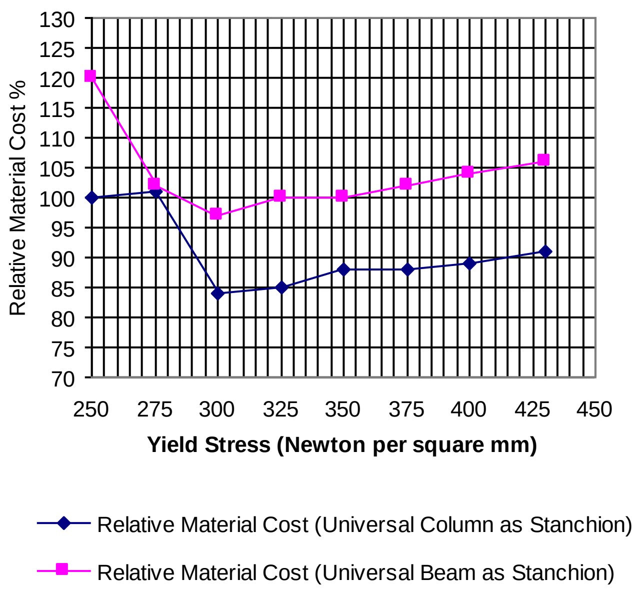

Fig. 2. Variation of yield stress with material cost of slender column.