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Axial Loads and Torsion in Steel Beams.

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Charges centrées et torsion dans les portiques étagés.

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1) *Introduction.*

In the course of the comprehensive experimental investigations carried out for the Steel Structures Research Committee referred to in another paper[1] tests were made on a number of existing buildings.[2] A great deal of information of the behaviour of steel frameworks was obtained and it is proposed here to draw attention to two points which are not generally appreciated.

2) *Partition of Bending Moment between Stanchion Lengths.*

It is set out in the regulations governing the erection of steel building frames adopted by many countries that the bending moment coming into a continuous pillar from a loaded beam may be regarded as divided between the pillar lengths above and below the level of the beam in direct proportion to the stiffnesses, that is: moment of inertia/length, of the upper and lower lengths.

The tests on buildings showed that, particularly when the steel frame was unclothed, the actual partition of moment between the upper and lower stanchion lengths was very different from that given by this rule.

Table 1 gives a comparison of the ratios of stanchion stiffnesses and observed bending moments for the single bay frame of an Hotel Building shown in fig. 1. It will be seen from the table that when load was applied to beam N° 301 F the ratio of the bending moments in stanchion N° 31 immediately above and below the level of the neutral axis of the loaded beam was 0.86 for the bare frame, and 0.76 after hollow tile floors had been laid and also after casing had been built round the stanchions, while the corresponding ratio of the stiffnesses was 1.00. A similar comparison is given in Table 2 for the single bay portion of an office building, fig. 2. These tables show that, except for the case of beam N° 301 G loaded, the lower stanchion length in the bare frame received more of the bending moment coming from the beam than the simple rule, quoted at the beginning of the paragraph, allows. This rule is based on a consideration of the simplest possible frame in which the top and bottom ends of the stanchion lengths are encastered and in which horizontal sway, or deflection of the beam,

[1] "A New Method for the Design of Steel Building Frames".

[2] Final Report of the Steel Structures Research Committee. H. M. Stationery Office London 1936

Table 1.

A Comparison of the Ratios of Stanchion Stiffnesses and Bending Moments immediately above and below the Neutral Axis of the Loaded Beam (Hotel Building, Single Bay Portion).

Loaded Beam	Stanchion	Ratio of Stiffnesses of Stanchion Lenghts	Ratio of Bending Moments		
			Bare Frame	Floors Laid	Stanchions Cased
301 H	S. 30	0·72	—	—	—
	S. 31	0·72	0·65	0·63	—
301 G	S. 30	1·00	—	0·91	—
	S. 31	1·00	1·27	0·76	—
301 F	S. 30	1·00	—	0·69	—
	S. 31	1·00	0 86	0·76	0·76
301 E	S. 30	0·55	—	0·5	—
	S. 31	0·55	0·35	0·53	—
301 D	S. 31	1·00	—	—	0·51

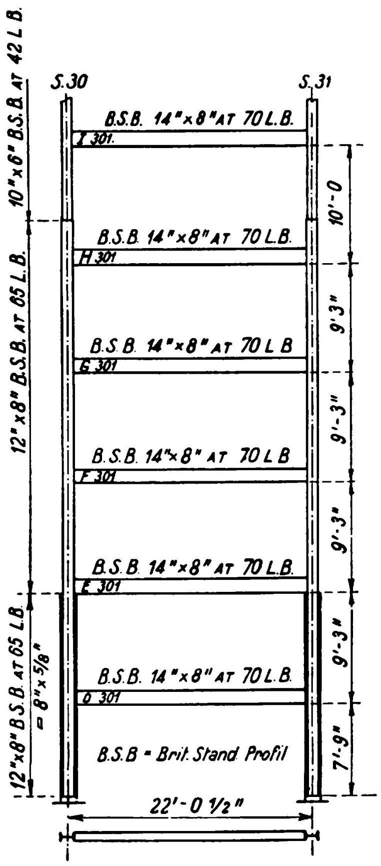

Fig. 1.
Single Bay frame of Hotel Building.

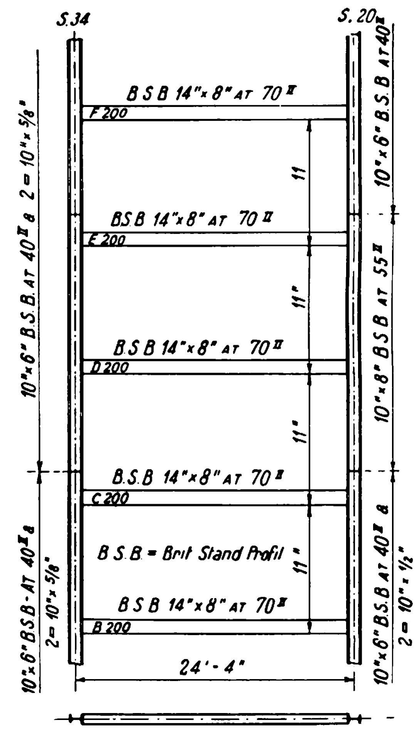

Fig. 2.
Single Bay frame of Office Building.

is prevented. In an actual frame there will, in general, be some rotation of the ends of the stanchion lengths remote from the loaded beam and also some sway, but neither of these effects could produce the change in partition shown by the tests. It would appear that the change is due to the development of an axial compressive force in the loaded beam.

Table 2.

A Comparison of the Ratios of Stanchion Stiffnesses and Bending Moments immediately above and below the Neutral Axis of the Loaded Beam (Office Building, single bay portion).

Loaded Beam	Stanchion	Ratio of Stiffnesses of Stanchion Lenghts	Ratio of Bending Moments		
			Bare Frame	Floors Laid	Stanchions Cased
200 D	S. 20	0·95	0·54	0·95	—
	S. 34	0·99	0 46	0.70	1·10
200 C	S. 20	0·78	—	0·47	—
	S. 34	0·94	—	0·73	0·76
200 E	S. 20	0·85	0·71	—	—
	S. 34	1·00	0·56	—	—

When a beam is loaded, flexure is induced and under normal conditions the top fibre suffers a contraction and the bottom fibre an extension. If, as in the frameworks under discussion, the beam is joined to a stanchion at each end by the common type of steelwork connection consisting of a stool and top cleat with or without web cleats, these changes in length of the beam tend to extend or open out the top cleat and to close up the stool, thus applying forces to the stanchion. When, as in the frames tested, the stanchions are not perfectly free to move, the behaviour of the cleat and stool is not identical, since, while the former extends comparatively easily by the bending of its vertical leg, the closing up of the stool is largely prevented, its vertical leg being in contact with the stanchion. This difference in behaviour has been shown clearly in later tests where the position of the centre of rotation of the end of the beam was determined experimentally. When the stanchions are not free to move, therefore, the forces applied through the cleat and stool are not equal and opposite, with the result that a net axial compressive force is developed in the loaded beam. The resultant load system applied to the stanchion by the beam must then consist of a couple and a transverse force. The former induces bending moments in the upper and lower stanchion lengths at the sections just above and below the loaded beam proportional, or very nearly so, to the stiffnesses of the upper and lower stanchion lengths. The effect of the bending moments produced by the transverse force is to decrease the moment in the upper stanchion length and to increase it in the lower, since the form of the bending moment diagram for the two stanchion lengths due to the transverse force is similar to that for a centrally loaded beam.

the flexural stresses in the fibres on the side remote from, but at the level of, the beam being tensile.

While an accurate estimate of the compressive loads could not be made from the strain readings in the beams, it was deduced from the bending moments in the stanchions that in beam N° 301 E, for instance, the axial load induced was approximately 1 ton when the applied transverse central load was 6.9 tons.

Table 3.

A Comparison of the Ratios of Stanchion Stiffnesses and Bending Moments immediately above and below the Neutral Axis of the Loaded Beam (Office Building, two bay portion).

Loaded Beam	Stanchion	Ratio of Stiffnesses of Stanchion Lenghts	Ratio of Bending Moments		
			Bare Frame	Floors Laid and Stanchion 47 Cased	Stanchions Cased
461 D	S. 47	0·98	0·69	0·72	0·74
461 E	S. 47	0·94	0.72	—	—

The observed partition of bending moment in internal stanchions is also of interest. While similar conditions to those already recorded were found, Table 3, in the centre stanchion of a symmetrical two bay frame of the Office Building, when beams on one side only were loaded, a very different state of affairs existed in an unsymmetrical frame, fig. 3, of the Hotel Building. Each of the beams N° 81, which were loaded in the test, was connected at one end to the centre of a wall beam and at the other to the web of the internal stanchion, on the other side of which was a much longer and heavier beam. The partition of bending moment coming from the loaded beam N° 81 is shown in Table 4 and it will be seen that

Table 4.

A Comparison of the Ratios of Stanchion Stiffnesses and Bending Moments immediately above and below the Neutral Axis of the Loaded Beam. Hotel Building, Internal Stanchion No. 8 A.

Loaded Beam	Ratio of Stiffnesses of Stanchion Lenghts	Ratio of Bending Moments		
		Bare Frame	Floors Laid	Stanchions Cased
81 D	1·00	1·21	1·13	—
81 F	0·75	1·24	0·96	1·01
81 G	0·89	1·34	1·42	—
81 H	0·67	1·35	1·39	—

in this case the upper stanchion length received a greater share than the simple design rule indicates. The reason for this is that in a multi-bay frame thrusts will be developed in both the loaded beam and in the beam on the other side of the internal stanchion to which they are connected. Where the sections of the beams are not very different, the thrust in the loaded beam will be the greater and the effect on the moments in the internal stanchion will be similar to that in the stanchions of a single-bay frame. This was the case in the two-bay frame of the Office Building. Where, as in the multi-bay portion of the Hotel Building, the loaded beam is of a much smaller section than that on the other side of the internal stanchion or the end conditions are different, the thrust in it may be less than the thrust in the unloaded beam. This will produce a different

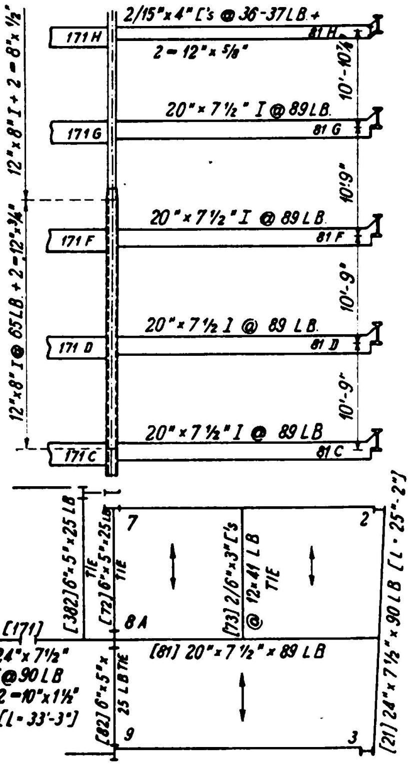

Fig. 3.
Unsymmetrical frame of Hotel Building.

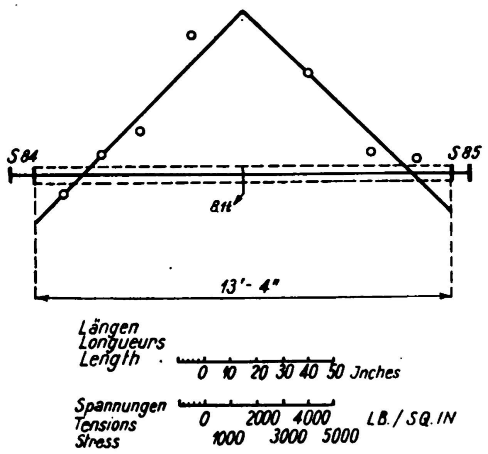

Fig. 4.
Observed stress due to torsion when a central concentradet load of 8.1 tons was applied to Beam No. 840 D.

form of partition of stanchion moment, the ratio of moments above and below the level of the beam being greater than the corresponding ratio of stanchion stiffnesses.

3) *Torsional Stresses in Beams of I section.*

The stress distribution in the frameworks of the buildings was found by measuring the strains at a number of sections of the steelwork. At any section where the distribution was required, four gauges were attached at the corners of the member and from the strains measured by the gauges the normal longitudinal stresses at the gauge positions were written down. These stresses could be split up into their components due to axial load, to bending about both principal axes, and to torsion. Owing to the difficulty of applying a truly central load, each loaded beam of the bare framework was subjected to some torsional couple, which produced larger torsional stresses in the beam than in the stanchions to which it was attached. It is, however, interesting to note that appreciable torsional stresses were found at some stanchion sections, due no doubt to the couples produced by imperfections in the beam to stanchion connections. Where a structure is clothed the floors and walls prevent, to a large extent, twisting of the members and it may be noted that in the buildings tested the torsional stresses observed in beams and stanchions were much smaller after floors, walls, and stanchion casing had been built than when the frames were bare. As a typical example, while a torsional stress of 507 lb/sq. in. was observed in a bare beam subjected to a concentrated load it had decreased to 94 lb/sq. in. when the same load was applied after a $6^1/_2$ inch thick hollow tile floor had been laid across the beam. In another case after walls and brickwork stanchion casing had been built the torsional stress in a stanchion length sank from 86 to 6 lb/sq. in.

While the presence of longitudinal stresses due to torsion may occasion no surprise, their magnitude is probably greater than the designer usually estimates. In a residential flats building it was found, fig. 4, that when a $10^{\text{in}} \times 4^1/_2{}^{\text{in}} \times 25^{\text{lb}}$ beam of the bare frame was subjected to a concentrated load of 8 tons, applied as accurately as possible to the centre of the section, producing a maximum flexural stress of 26,500 lb/sq. in., a longitudinal stress, due to torsion, of as much as 6200 lb/sq. in. was present. The eccentricity of loading was estimated to be 0.20 inches so that the applied couple giving rise to this stress was only 1.6 ton. in.

It appears that when a beam in a steel building frame, connected to stanchions at its ends by the usual type of flange cleat connections, is subjected to a twisting couple at the centre the flanges deflect laterally but remain almost horizontal. This suggests that the torsional rigidity of the member is supplied largely by the flanges acting as beams and that the effect of the torsional couple is almost that of two equal but opposite forces, at right angles to the axis of the beam, lying in the planes of the flanges.

While the presence of floors would prevent stresses of the order shown in fig. 4 it seems probable that, even in clothed buildings, where a load-carrying beam frames into one side only of the web of another beam, as shown in fig. 3, large stresses not usually assessed for design purposes are set up.

Summary.

In the course of the tests on five existing buildings mentioned in another paper, "A New Method for the Design of Steel Building Frames", a great deal of information of the behaviour of steel frameworks was obtained. Two points are discussed in this paper.

It is set out in the regulations governing the erection of steel building frames adopted by many countries that the bending moment coming into a continuous pillar from a loaded beam may be regarded as divided between the pillar lengths above and below the level of the beam in proportion to the stiffnesses of the upper and lower lengths. The tests showed that the actual partition of moment was very different from that given by this rule.

Attention is also drawn to the large longitudinal stresses sometimes set up in the flanges of the members of steel framed buildings due to torsion.