TESTS ON AN AXIALLY LOADED STEEL ENERGY ABSORBER

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ABSTRACT:

Tests on a steel energy absorber loaded axially in push-pull are described. The device is intended for use in diagonal bracings or in other convenient positions in building frameworks. It was concluded that the device tested would perform adequately as an energy absorber at a stroke of ±6 mm when the strain would be about ±3% and the life about 80 cycles. Care is needed in restraining such a device against buckling in the compression part of the cycle and full-scale testing is required to establish performance characteristics in an actual structure.

1. INTRODUCTION:

Up to the present time, steel energy absorbers so far developed at this Laboratory to control earthquake motions have utilised elements in bending and torsion(1). The tests described below, requested by the Ministry of Works and Development, were on an axially loaded mild steel bar, constrained to contain the buckling induced in the compression part of the tension/compression cycle. This type of energy absorber has been suggested for applications where inter-storey drift in buildings is to be minimal, when they would be located typically in diagonal members which only attract load under lateral loading. Steel absorbers performing a similar function have already been used in the diagonal members of a government building completed in 1980 in Wanganui (Fig. 1). Wind, as well as earthquake, would load this type of energy absorber, but normally not sufficiently to cause yield in the absorber, although in one application to the 110-storey World Trade Center in New York 10000 dampers employing a viscoelastic plastic were installed to control wind motions(2). The location of the absorbers is shown in Fig. 2, and such a location would be equally suitable for earthquake loading.

2. DESCRIPTION OF ABSORBER

The device tested is shown in Fig. 3. This is a model of a full-scale device. The actual full-scale size would depend on the performance required in the structure in terms of energy absorption. A 25 mm rod in black mild steel was machined down to a diameter of 16 mm over four lengths of 50 mm, the parallel length at 16 mm diameter being about 172 mm overall for the whole specimen. As the device was to be loaded cyclically in tension and compression in an axial direction, a steel tube 300 mm long was fitted over the outside of the rod to give buckling support on the compression stroke. The internal diameter of the tube was 26 mm giving an all round clearance on the outside of the bar of 0.5 mm.

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3. TEST PROCEDURE:

The bar was set up in the Instron Testing Machine with the loading grips as close to the machined length as possible to avoid buckling effects. The device was cycled through a recorded movement of ±1 mm initially, without the support tube in place, producing the loop shown in Fig. 4, the device evidently remaining elastic. The step in the loop on zero load was caused by slack in the machine loading system.

The test was then repeated at ±3 mm producing the loop shown in Fig. 5. The device yielded at about 56.4 kN when the stress was 280 MPa (see Appendix). However, on compression there was a very much reduced load caused by incipient buckling which produced the asymmetrical loop shape shown and it was decided to fit the support tube for the remaining tests.

Further tests were carried out at recorded movements of ±2, 3, 4, 5 and 6 mm producing the symmetrical loops shown in Figs. 6-10. At ±6 mm some buckling of the two end sections occurred, where there was least support derived from the tube (photos Figs. 11 and 12) and the testing was stopped.

The peak loads obtained are tabulated in Table 1. In the first tests, with no support against buckling, the loads in tension were greater than those obtained in compression. With the tube in place, however, for ±5 and 6 mm the tensile loads were less than the compressive, indicating that the specimen was binding in the tube.

4. STRAIN IN ABSORBER

At the recorded movement of ±6 mm, the net movement of the yielded portions was estimated to be ±4.79 mm, the remainder of the movement being slack in the machine fixings (±0.20 mm), movement in the machine fixings (±0.81 mm) and movement in the unyielded portions of the absorber (±0.20 mm), as delineated in the Appendix. For 200 mm of yielded bar thus gives a strain of ±2.4%. At this strain level the expected fatigue life in push-pull would be about 100 cycles, based on previous work carried out on steel specimens (Fig. 13)(3).

The elastic strain at yield was not

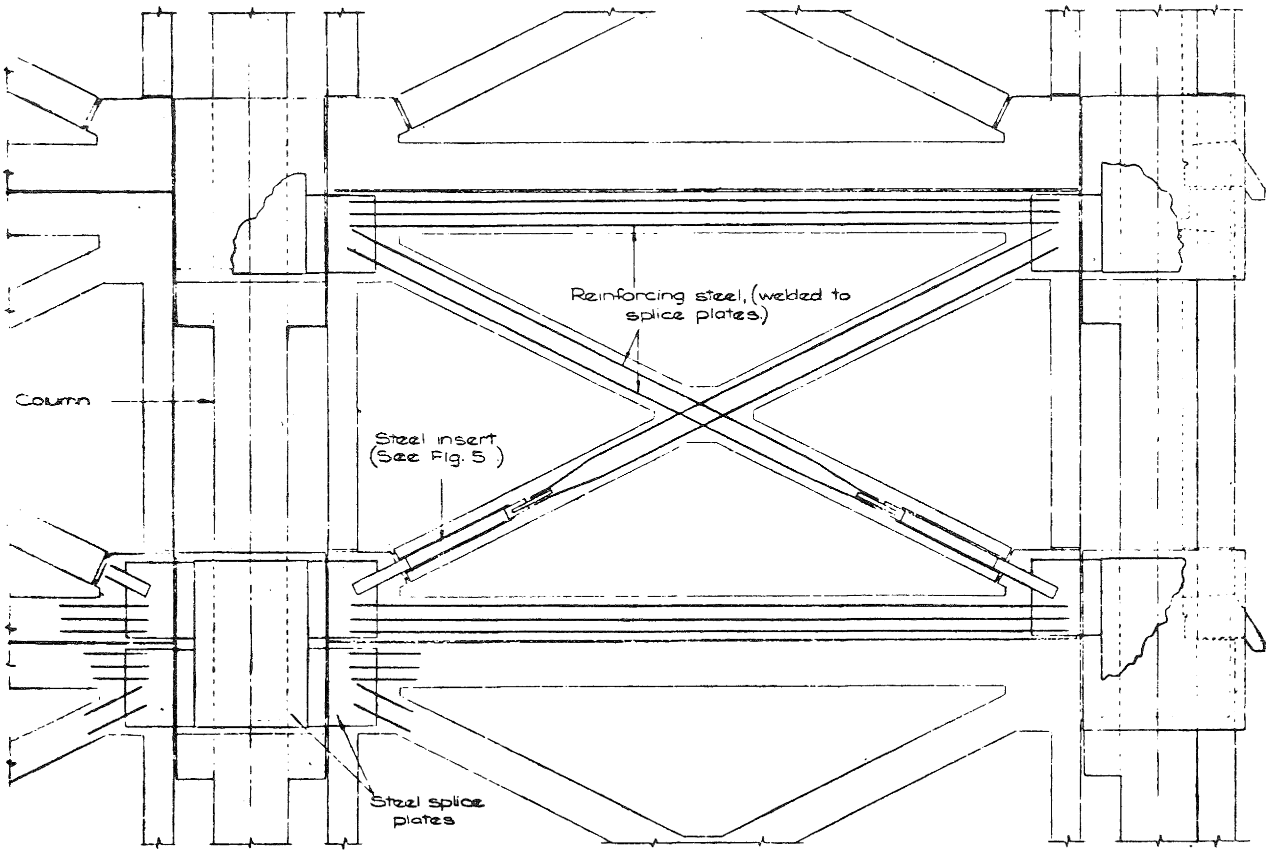

Fig. 1(a) Wanganui Building: Precast Concrete Wall Panel Details.

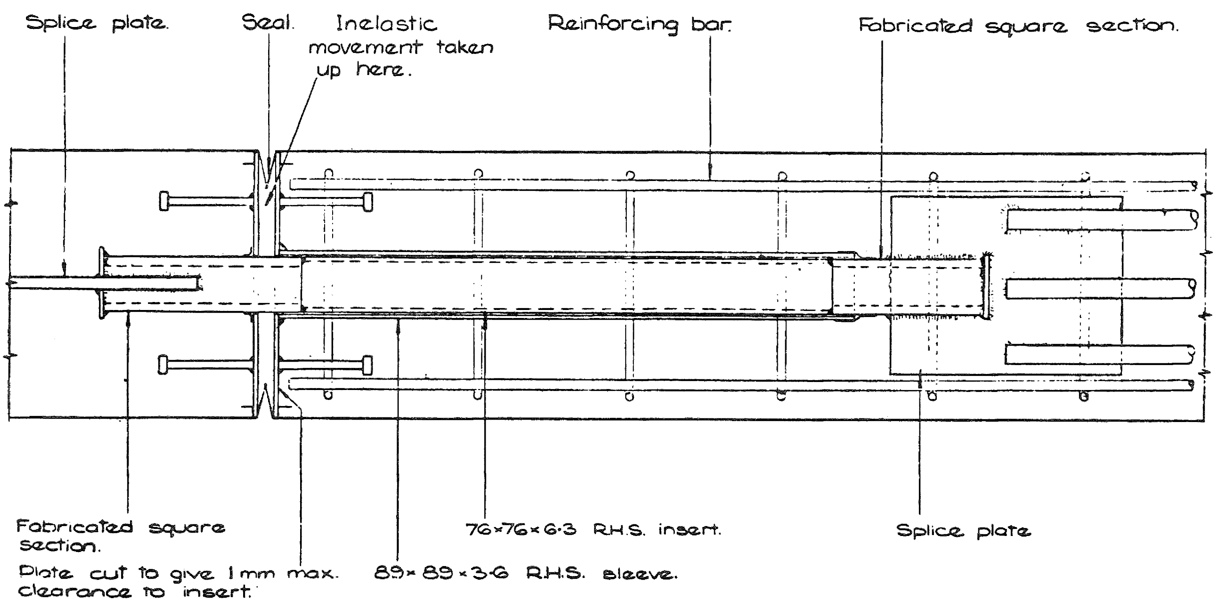

Fig. 1(b) Wanganui Building: Steel Insert Details.

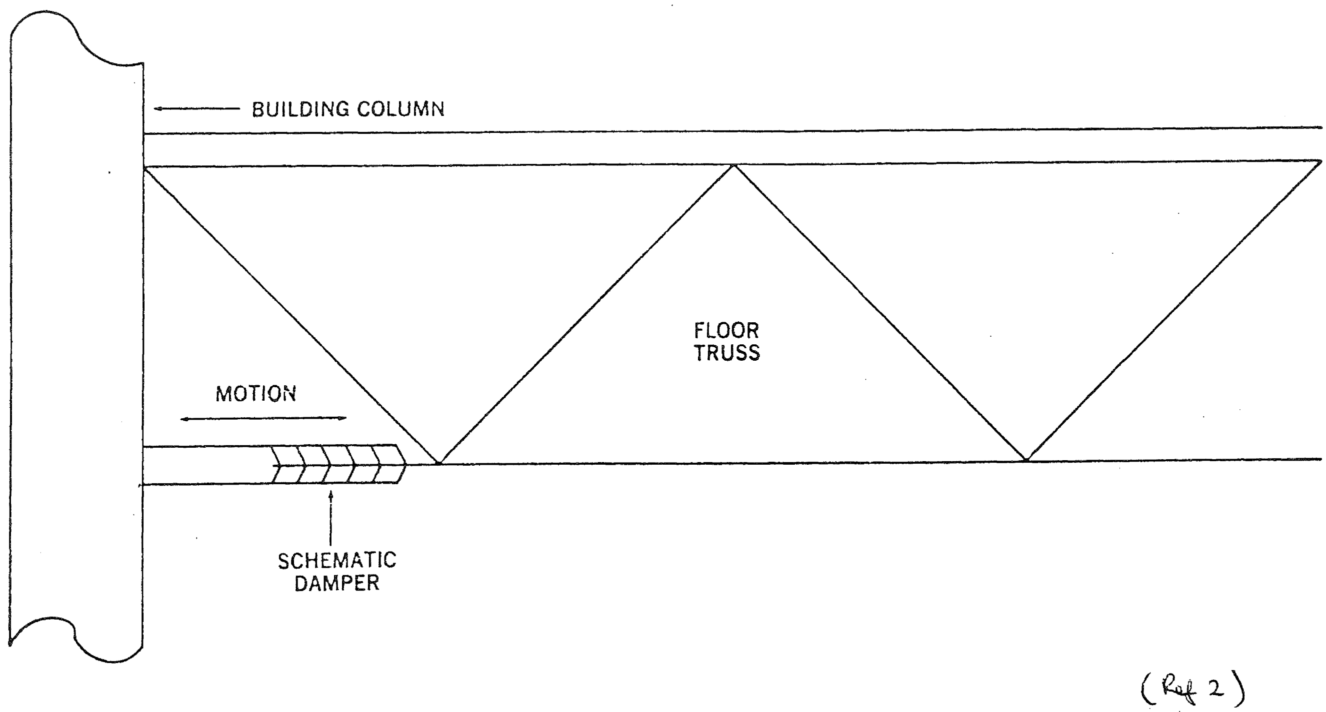

Fig. 2 Installed Location of Viscoelastic Damping Unit World Trade Centre (Ref. 2)

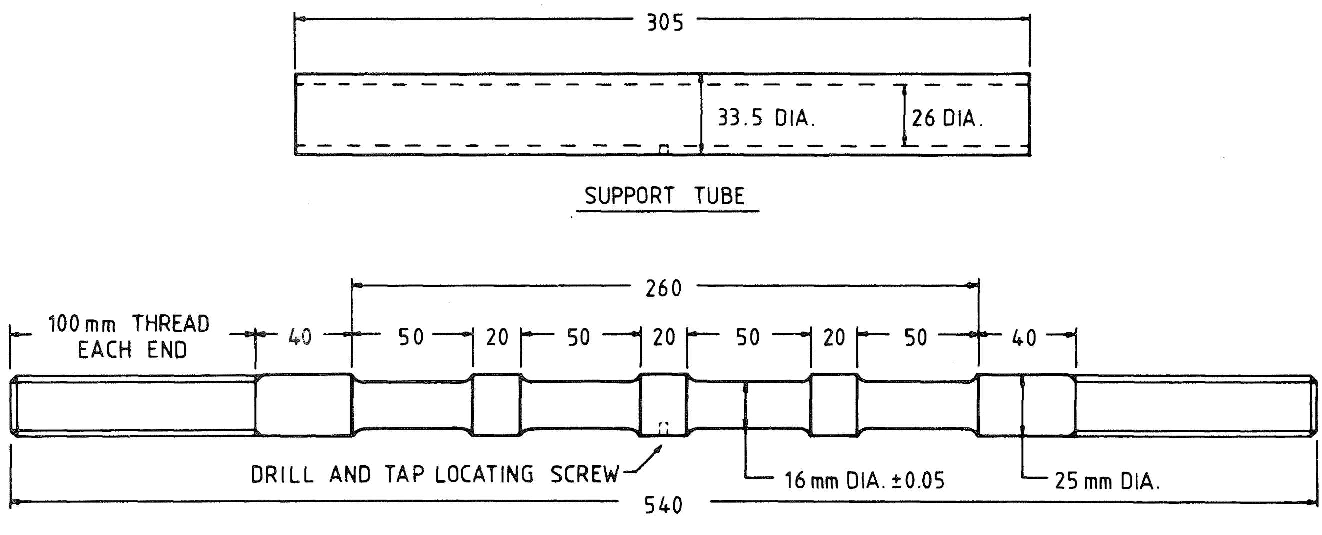

Fig. 3 Detail of Bar Tested and Support Tube

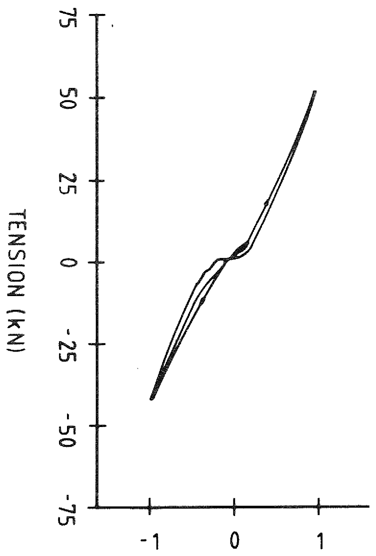

Fig. 4 ±1mm

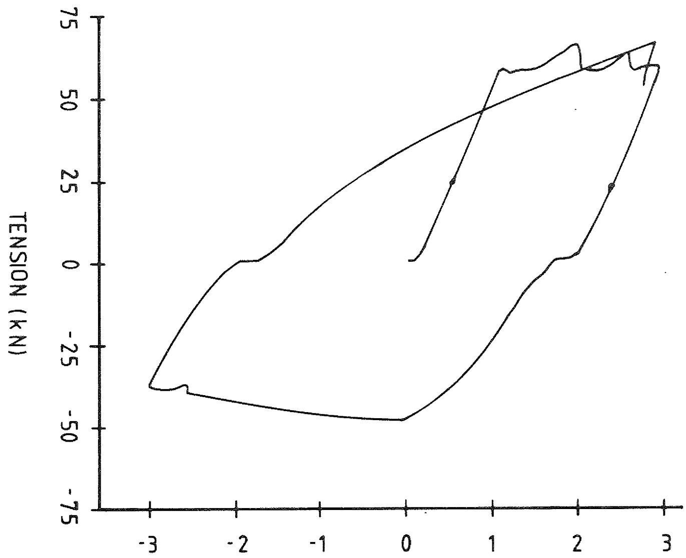

Fig. 5 ±3mm
NO SUPPORT TUBE

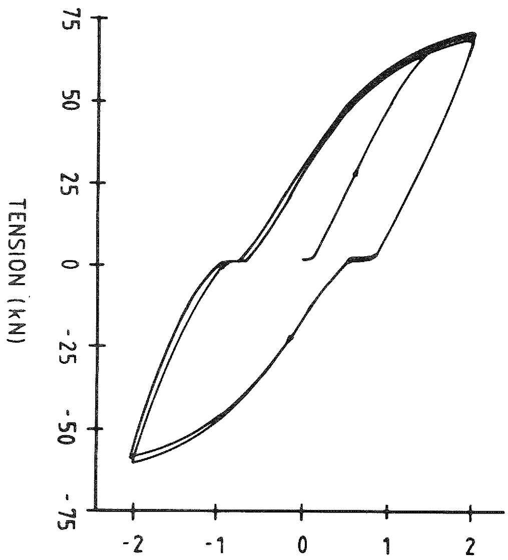

Fig. 6 ±2mm
SUPPORT TUBE IN PLACE

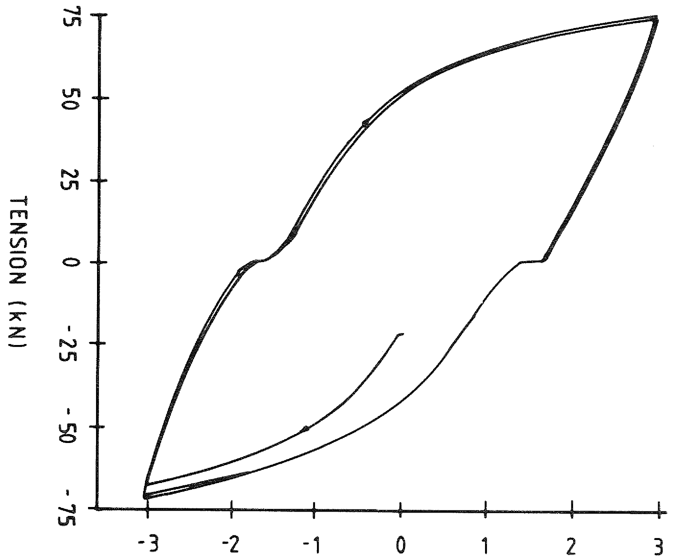

Fig. 7 ±3mm

measured but can be estimated taking the modulus of elasticity for steel to be 20 GPa (see Appendix). This gives a strain at yield of about 1400 microstrain. The ductility factor for the yield portions, i.e. the ratio of strain at an overall movement of ±6.0 mm to the strain at yield, is then about 17. For the absorber length between joins the ductility factor was about 12.5.

5. COMMENT:

In the tests cycling was performed about a mean position determined by the test machine. It is worth bearing in mind, however, that in a free position in a structure, there would be a tendency for the device to "drift" in terms of its overall length unless used within the elastic range of a structure. This is because of the differences which would arise in the tension and compression parts of the cycle. This phenomenon has been observed in other energy absorbers, both in steel and lead, that as soon as plasticity develops there is a tendency for a flow or drift in some preferred direction. This is consistent with the structure finishing up permanently distorted, which may lead to an early failure of the absorber due to excessive movement in one direction. The performance of energy absorbers in full-scale structures under earthquake loading is a subject for research. Where lead-plug energy absorbers are used in laminated rubber bearings in base-isolation systems there is a positive elastic return and the problem does not arise.

The effectiveness of the device will depend on the adequate restraining of the buckling in the compression cycle. Some earlier tests were carried out with a specimen about 200 mm longer, but with the support tube the same length as in the tests reported. It was found that the tensile loads were much greater than the compression ones because of the bowing of the device between the fixings in the test machine. Accordingly, the device was shortened to the length shown in Fig. 1. Ideally compression support should cover all of the exposed length of the device.

6. CONCLUSION:

The device tested performed adequately as an energy absorber at the stroke of ±6 mm when the strain was about ±2.4% and the expected life would be about 100 cycles. Care is needed to restrain such a device in compression over its entire length and full-scale testing is required to establish performance characteristics in an actual structure.

ACKNOWLEDGEMENTS:

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7. REFERENCES

(1) Skinner R.I. et al. Hysteretic dampers for the protection of structures from earthquakes, Bull. NZ Nat. Soc. Eq. Eng. Vol. 13, No. 1, March 1980.

(2) Caldwell D.B. Vibration damping in World Trade Center using viscoelastic material. The 3M Company, New York.

(3) Tyler R.G. and Skinner R.I. Testing of dampers for the base isolation of a proposed four-storey building against earthquake attack. Proc. 6th Australasian Conference on the Mechanics of Structures and Materials, Un. of Canterbury, 1977.

8. APPENDIX - Calculation for absorber performance

8.1 Yield condition

Yielded portions of absorber (total length 200 mm diameter 16 mm)

Area = 201.1 mm^2
Stress = 56.4 x 10^3/201.1 = 280.4 MPa

Calculated strain, based on an assumed modulus of elasticity for steel,

E = 20 GPa = 1402 microstrain

Calculated extension over the 200 mm length = 0.28 mm

Remainder of absorber between machine fixings

(total length 200 mm, diameter 25 mm)

Area = 490.87 mm^2

Stress = 56.4 x 10^3/490.87 = 115.7 MPa

Calculated strain for E = 20 GPa = 579 microstrain

Calculated extension over the 200 mm length = 0.12 mm

Slack

From the graphs the slack in the machine fixings was about ±0.2 mm.

Total recorded movement

The chart recording showed a total movement of about 1.08 mm at yield.

Elastic movements in machine fixings

This is inferred as the total recorded movement less the elastic movements in the absorber and the slack, detailed above, i.e. 1.08 - 0.2 - 0.12 - 0.28 = 0.48 mm.

8.2 Condition at ±6 mm recorded movement

Elastic movements in machine fixings

This will be greater than for the yield position in proportion to the loads and is taken as

Movement = 0.48 x (89.05 + 100.52)/2 x 56.4 = ±0.81 mm

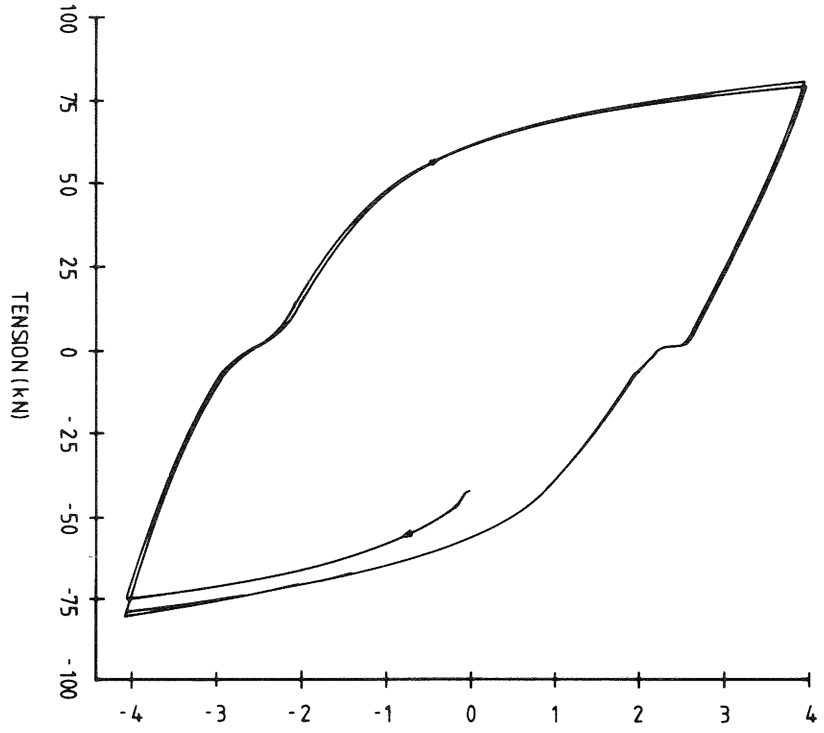

Fig. 8 ±4mm

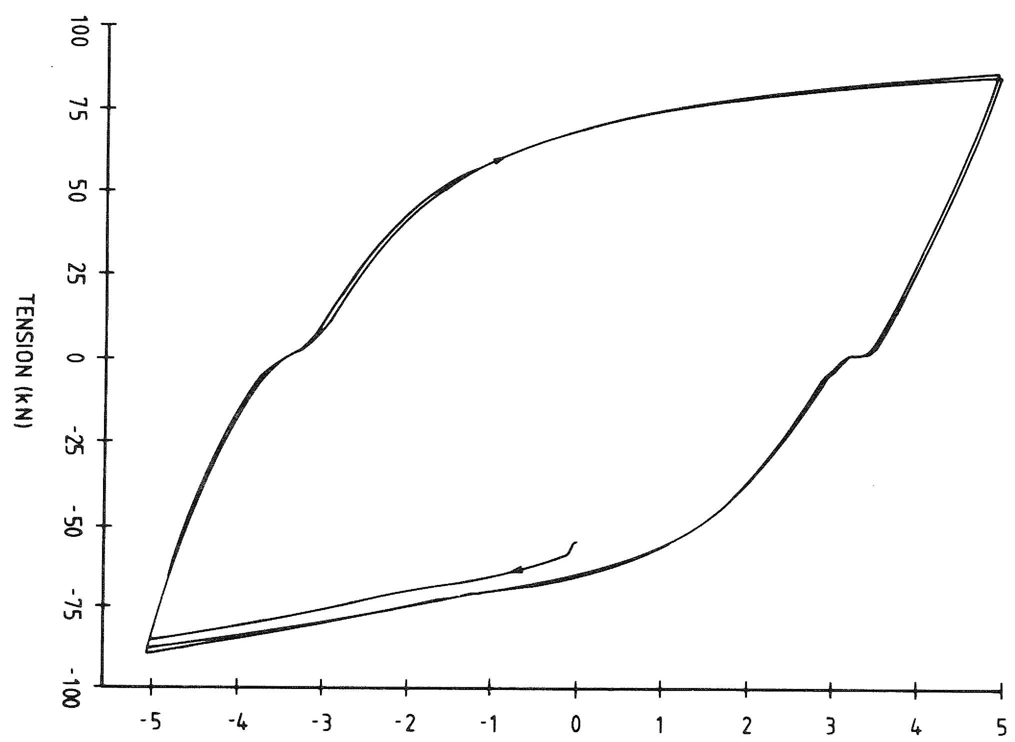

Fig. 9 ±5mm

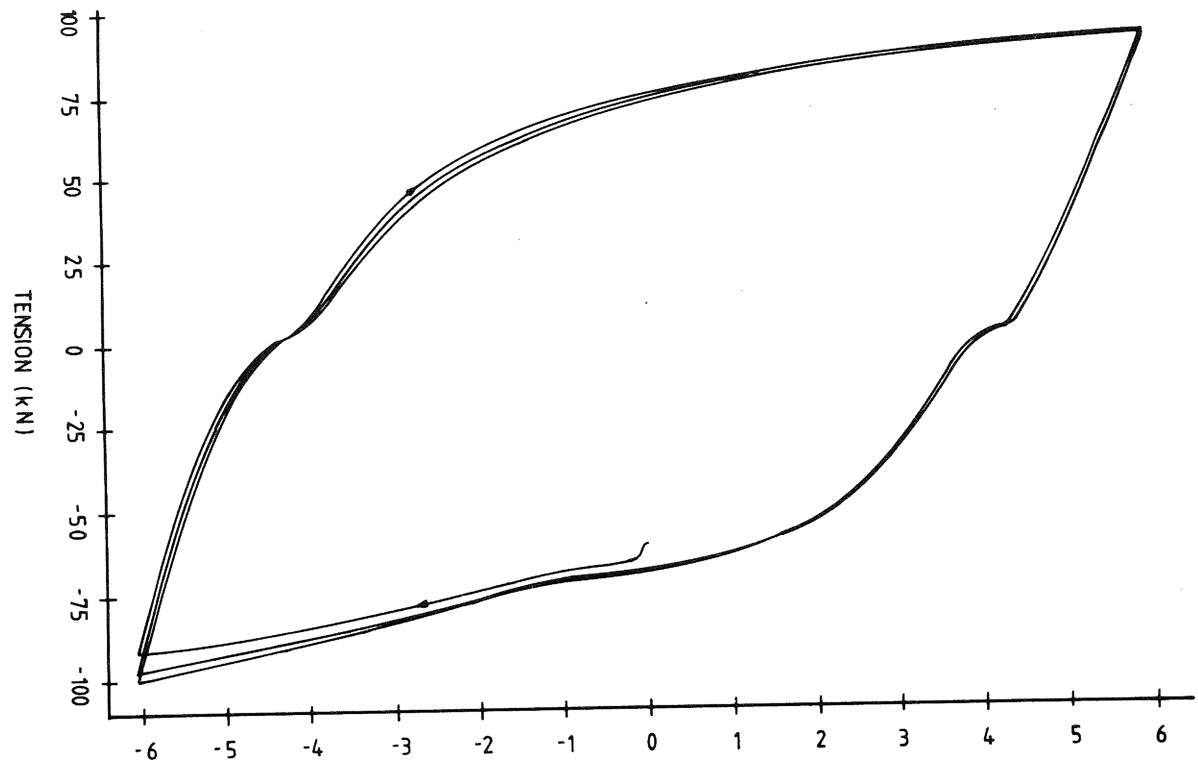

Fig. 10 ± 6mm

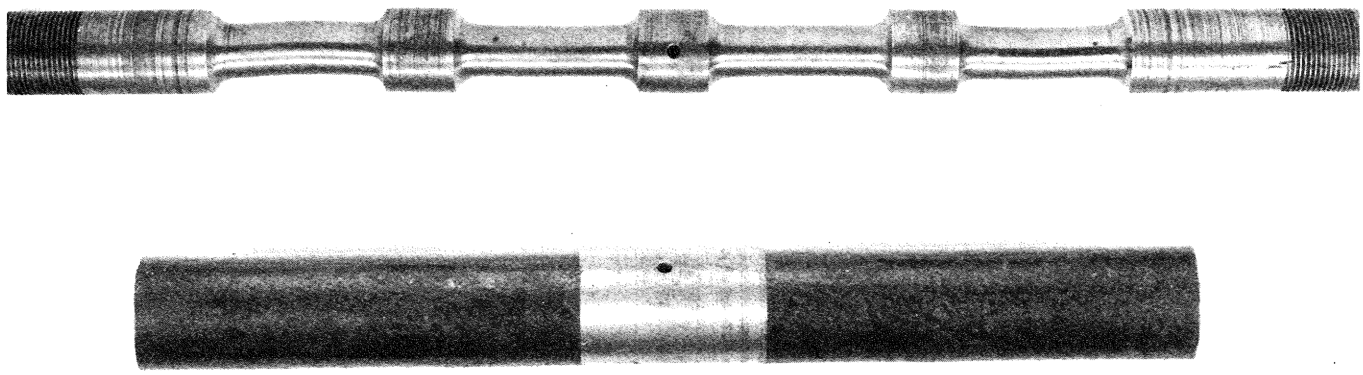

Fig. 11. Bar and Restraining Tube (after testing).

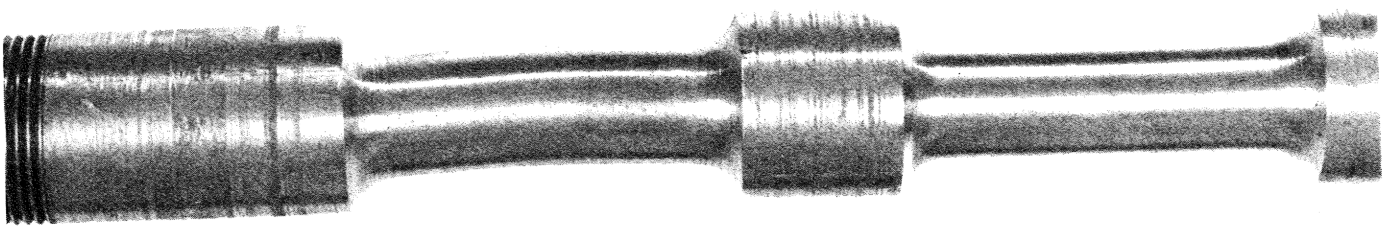

Fig. 12. Local Buckling of Bar after Testing.

Elastic movement in unyielded portions of absorber

This also will be proportionately greater

Movement = 0.12 x (89.05 + 100.52)/(2 x 56.4) = ±0.20 mm

Slack

This is as previously, i.e. ±0.20 mm.

Net movement in yielded portions of absorber

Net movement in yielded portions = recorded movement ±6 mm, less the elastic movements and slack delineated above

i.e. ± (6 - 0.80 - 0.20 - 0.20) = ±4.79 mm.

This gives a strain in the yielded portions = ± 4.79/200 = 2.4%

Ductility factor for yielded portions only = $2.395 \times 10^{-2}/1402 \times 10^{-6}$ = 17

Ductility factor for specimen between machine fixings

= (6 - 0.81 - 0.20)/(0.12 + 0.28)

= 12.5.

TABLE 1

Peak Loads Obtained on Cycling (kN)

Range of Test Machine Movement (±mm)	First Series (without restraining tube)		Second Series (restraining tube in place)	
	Peak Tensile Load	Peak Compression Load	Peak Tensile Load	Peak Compression Load
1	51.48	44.13	-	-
2	-	-	69.14	59.14
3	64.73	61.78	73.75	69.63
4	-	-	79.44	79.44
5	-	-	85.81	88.26
6	-	-	89.05	100.52

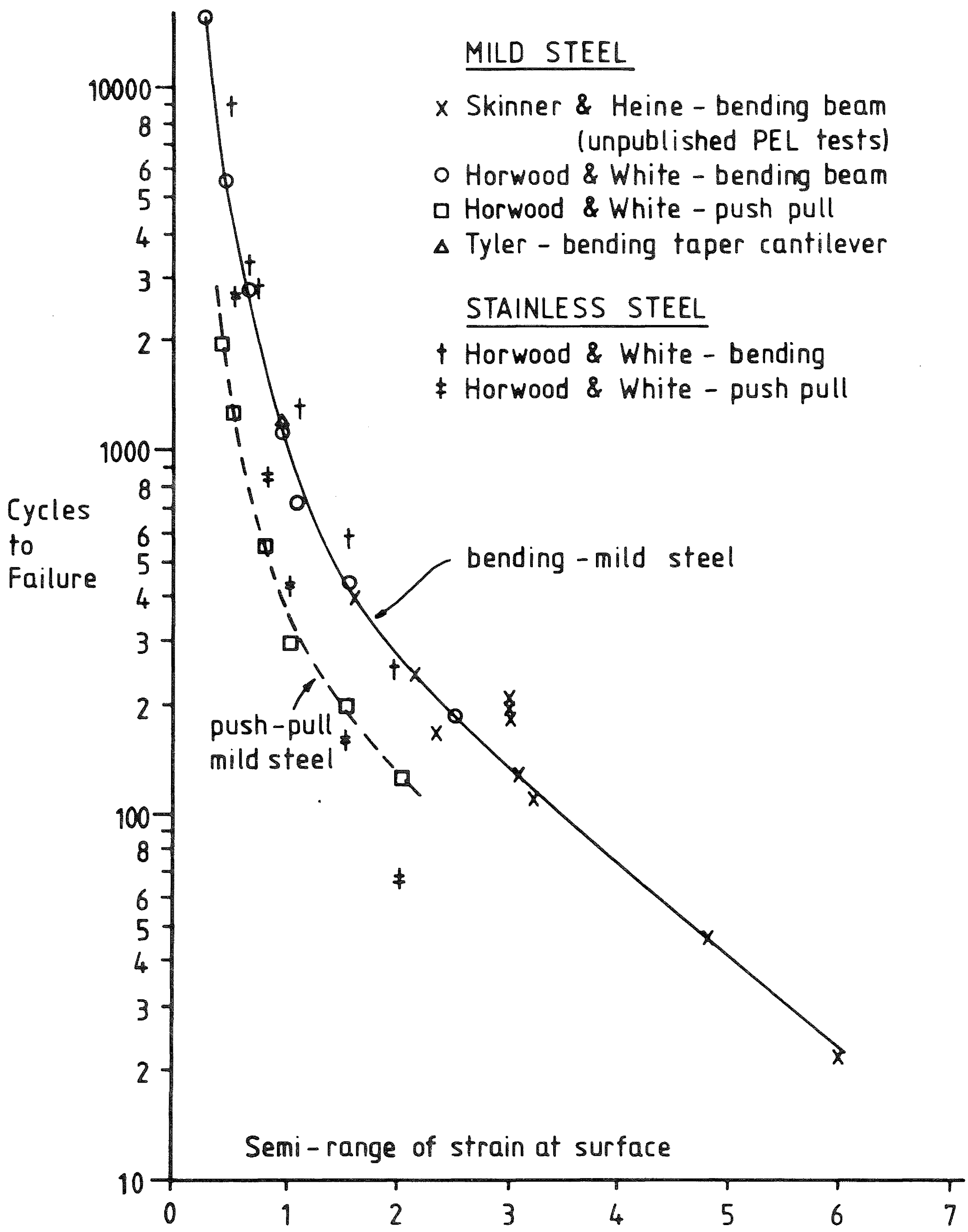

Fig. 13 Low Cycle fatigue Life for Mild and Stainless Steel