EXPERIMENTAL STUDY ON COLD FORMED STEEL PURLIN SECTIONS

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Abstract: Cold formed steel purlins are the widely used structural elements in India. Practically 'Z' sections are provided, where the span of the roof purlins is sloped and the length of the span is maximum. The objective of this investigation is to study the behaviors of cold formed steel 'Z' purlin sections. Three members of Zinc coated cold formed 'Z' sections and three numbers of ordinary cold formed 'Z' sections were tested under two point bending with simple supports. The results obtained from experiments were compared with theoretical deflection. The theoretical and actual load carrying capacity of the section is compared. The load vs. deflection behavior is also presented and discussed.

1. Introduction

The name of the cold formed section itself implies that shapes are formed in cold conditions. For lighter to medium loads and smaller to medium spans use of cold formed sections are more economical than that of rolled sections. Cold formed sections fabricated from sheets, strips, and plates in roll forming machines or press brakes or bending brake operations.

1.1 Uses of Cold Formed Sections

In 1950, England & United States of America started to use cold formed steel sections in building constructions. Since 1946 the use and development of thin walled cold formed steel construction in the United States have been concentrated by the essence of various edition of the "Specimen" for the design of cold formed steel structural members of American Iron and Steel Institute (AISI). It is mainly based on the Research works carried out of Cornell University. Because of their high strength to weight ratio and reduction of dead weight, cold formed steel sections become attractive building materials.

The cold formed steel sections are used in Car bodies, Railway coaches, various types of equipments, Storage racks, Highway products and Bridge construction, Industrial structures, Transmission line towers and multistoried buildings.

In recent years, the cold formed steel sections have gained considerable prominence over hot rolled sections. Two main reasons attribute to the above fact are their economy achieved for relatively lightly load and moderate spans and their sectional configurations which make the usual hot rolled sections uneconomical.

The main process of cold formed steel structural elements involves forming steel sections in cold state sheets at uniform thickness. The thickness of steel member ranges from 0.4 mm to 6.4mm. The cold forming operation increases the yield point and ultimate strength of the steel sections.

1.2 Advantages of cold formed steel

As compared with thicker hot-rolled shapes, more economical design can be achieve for relatively light loads and / or short spans.

Unusual sectional configurations can be economically produced by cold forming operations and consequently strength to weight ratios can be obtained.

Load carrying panel and decks can provide useful surfaces for floor roof and wall construction and in other cases they can also provide enclosed shells for electrical and other conduits.

Cold rolling can be employed to produce almost any desired shape to any desired length. Zinc coated metal can be formed.

1.3 Recommendations of AISI – Specification

A 'Z' section is a point symmetrical about a point (centroid). 'Z' sections having equal flanges are a point symmetric section. 'Z' section will buckle laterally at a lower stress than 'I' beam or channel section for $L^2 s_{xc} / d\, I_{yc}$ ratio. A Conservative design approach is used in the AISI (American Iron And Steel Institute) specification in which the allowance stresses for Z – sections are one half those permitted for I – beams or channels with the same $L^2 s_{xc} / d\, I_{yc}$ ratio in the elastic range. Numerically, the following formulas are included. The AISI

Specification for the design of Z-beams bent about the centroidal axis perpendicular to the web.

When, $L^2 s_{xc} / d\, I_{yc}$ is greater than $0.18\, \pi^2 E C_b / F_y$ but less than $0.9\, \pi^2 E C_b / F_y$

$$F_b = 2/3\, F_y - (F_y^2 / 2.7\, \pi^2 E C_b) \times (L^2 S_{xc} / d\, I_{yc}) \qquad (1)$$

When, $L^2 S_{xc} / d\, I_{yc}$ is greater than or equal to $0.9\, \pi^2 E C_b / F_y$

$$F_b = 0.3\, \pi^2 E C_b (d\, I_{yc} / L^2 S_{xc}) \qquad (2)$$

In the above,

L = the unbraced length of the member

I_{yc} = The M.I of the compression portion of a section about

The gravity axis of the entire section parallel to the web,

S_{xc} = Compression section modulus of section about major axis Ix divided by distance to extreme compression fiber.

C_b = Bending coefficient from graph.

E = Modulus of elasticity.

d = Depth of section.

The figure 1 shows the relationship of F_b and $(L^2 S_{xc} / d\, I_{yc})^{1/2}$ for Z section

For **Z** sections, when the load in the plane of the web, the section does not rotate in the same manner as channels because the shear center coincides with its centroid. However, in view of the fact that in Z sections the principal axes are oblique, even though such section is loaded vertically it will deflect vertically and horizontally. If the section deflects horizontal direction, the applied load will also move with the beam and is no longer in the same plane with the reactions at both ends. As a result, the section deflects horizontal direction; the applied load will also move with the beam and is no longer in the same plane with the reactions at both ends. As a result, the section also twists in the addition to vertical and horizontal deflections. The additional stress caused by the twist reduces the load carrying capacity of the member.

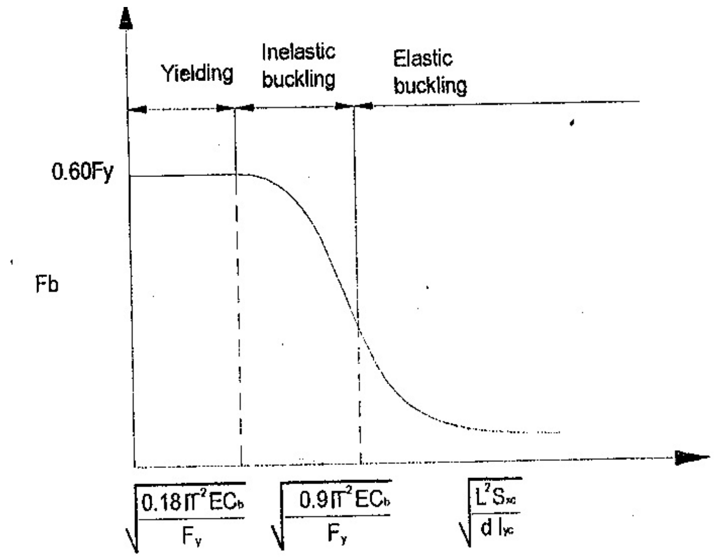

Figure 1: Allowable Stress for lateral Buckling of Z-Shaped Beams

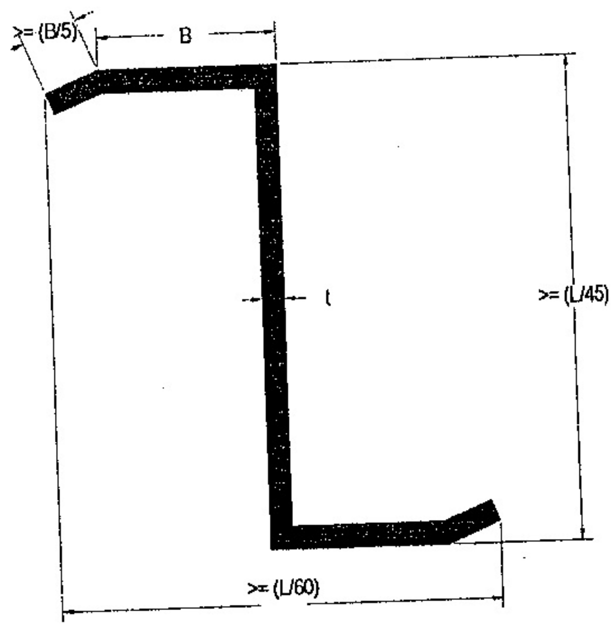

Figure 2: Z Purlins and Sheeting Rails

The investigation which was carried out by Zetlin and Winter to study the bracing requirement for Z-beams consisted of testing 19 beams of three different shapes. An approximate method of analysis indicated that the braced Z-beams can be analyzed in the same way as braced channels, except that the fictitious horizontal loads PL applied at the point of each actual vertical load should determined by

$$PL = P(I_{xy}/I_x) = PK'. \quad (3)$$

For this reason, the AISI Specification specifies the same bracing requirements for channels and Z sections with an exception that the term K' should be determined by I_{xy}/I_x.

Author Dr.Wei-wen-yu has the values of shear center from X & Y axis & the warping constant (W_c)

$$Xo = 0$$

$$Yo = 0$$

$$Wc = \frac{(tb^3a^2/12)(b+2a)}{2b+a} \quad (4)$$

2. Behavior of Cold Formed Steel Purlins

The British Standard (BS5950): Part 5: 1987, Section 9 says that, where Z purlins with lips are designed in accordance with these simplified rules, the following recommendations apply.

1. In design purlins, un factored loads should be considered.

2. The imposed load should be determined in accordance with BS code in the case of purlins sheeting rails, local wind pressure & suction need not considered but should be taken as not less than 0.60 kN/m^2. For agricultural buildings, reference should be made to BS5502.

3. The cladding and fixing should be capable of providing lateral restraint to the purlins and carrying the component of load in the plane of roof slope.

4. The purlins should be considered to carry the component of load normal to the roof slope. The purlins may also be allowed to carry a nominal axial load due to wind restraint forces, provided the axial stress on the full cross section due to these causes does not exceed 6 N/mm^2.

5. The design rules apply to the purlins up to 8.0m span in roof slopes up to 22.5 for spans up to 5.0m, the purlins may be nominally simply supported with a two bolt connection, but for spans above 5.0m the purlins should be continuous or provided with sleeves or splices with a moment capacity equal to that of the member. In multi span conditions, the design rules may be used provided adjacent spans do not differ by more than 20%.

6. Where the purlin span exceeds 4.6 m, anti-sag bars should be provided so that the laterally unsupported length does not exceed 3.8. In pitched roof buildings, the anti sag bars should be tied across the apex; in mono pitch roofs, the anti sag bars anchored to a rigid apex supports or their forces transferred diagonally to the main frames. Erection and wind uplift bracing should be employed as normal practice.

7. The purlin lips may be splayed outwards at an angle not exceeding 10. In calculation of section properties, the width of the lips should be taken as one-fifth of the flange width.

8. The purlin cleats should provide torsional restraint to the purlin not less than that normally given by angle cleats.

2.1. Design guidelines for Cold Formed Steel Purlins

BS 5950: Part 5:1987 given the following Design rules for the cold formed steel purlins with reference the fig. 2 The design rules given in this section may be used an alternative to the analytical methods given in sections two to eight or the testing methods given in section ten. The design rules apply to all steels with yield strength Yx not less than 250N/mm^2.

100t > Overall depth > L /45

Total width over both flanges > L/60

Overall width of compression flanges / thickness B/t < 35

Width of Lip > B/5

For simply supported purlins: Section modulus > WL / 1800 $(cm)^3$

3. Fabrication of Test – Rig.

In the conventional UTM's and the loading frame available in the laboratory. Only one unidirectional loading can be applied. Hence to facilitate the application of two concentrated loadings a separate Test – Rig was fabricated for the present study.

To simple supports were made using I sections of 1m height as a columns. These 2 I sections were welded centrally at bottom with the base plate of size 600mm x 600 mm. These 2 I section columns were fixed by bolts with masonry brick pillars to increase the height of the column. This facility was made to reduce the distance between the specimen and to the hydraulic loading jack.

The center to center distance between these two columns is 3m. Because the length of the column was 3m, while pouring 1:2:4 concrete for brick pillar bed 4 numbers of 12mm bolt was embedded into the foundation unit. Then the 1 section columns along with the bas plate and nuts at a c/c distance of 3m, To fix the 'Z' section in the support a base plate with 8 mm thickness were welded on the top of 1 sections. And to reduce the rotation of 'Z' section 2 numbers of angle section 150mm x 12mm were welded on the base plate.

The angle sections are placed such that, the web of the angle sections are placed on either side of the web of the 'Z' section. The bottom flange of the angle section is cut-off from the base plate to certain extent to avoid overtopping at the bottom flange of 'Z' section. Sufficient number of bolts is projected from the web portion of the angle to keep track the vertically of the web portion of the 'Z' section. It also avoids the lateral movement of the 'Z' section along its length during loading condition. This setup allows the 'Z' section, bend along its supports.

Two steel boxes are made at 2 loading points. The size of the hollow rectangular box section is of 200mm x 200mm. The 200mm x 250 mm (depth) sides are made hollow to insert the 'Z' section tested. Inside the hollow box a plate is welded from the top without touching the bottom flange near the web face of the 'Z' section to avoid the rotation at loading point. The schematic diagram of this steel Test Rig is shown in figure 3.

3.1 Test specimen details

All the specimens used in the present investigation are factory made products. They are produced by TIGER STEEL INDUSTRIES Mumbai. Three numbers of zinc coated 'Z' section with lips and three members of ordinary 'Z' section with lips were obtained & used as test specimen are in 3.0m. The sections are stiffened by a lip bent at 22.5 to horizontal on both flanges. The maximum depth of the section is 250mm, and the minimum depth is 200mm. The thickness, length of the flange, length of lips varying based on the depth of 'Z' sections, as per AISI, BS codes.

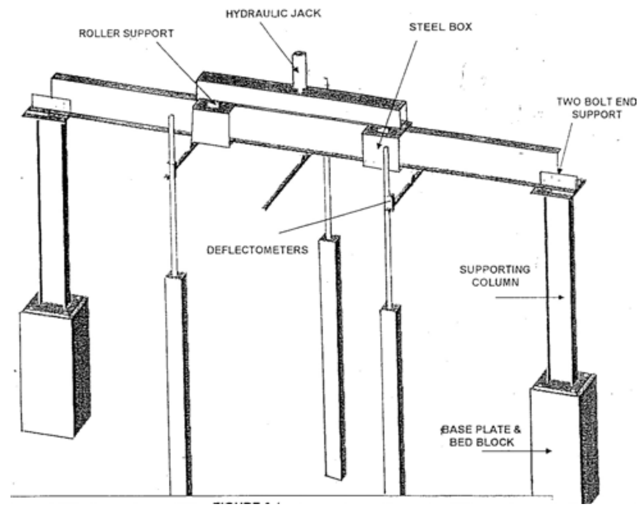

Figure 3: Schematic Diagram of Loading Setup

Two numbers of 12 mm holes were drilled in the specimen to connect the ends inside the angle section to avoid the lateral rotation to simulate the simple support. Two concentrated loads were applied on the 'Z' section by using two numbers of roller supports. Over that, a box section of 8mm thickness is used to apply the load was used to distribute the loads equally to roller supports. A hydraulic jack between the loading frame and box section is to apply the load.

Two steel boxes are used at 2 loading points to transfer the load to the specimen. The size of the hollow rectangular box section is of 200mm x 200mmx250mm. The 200mmx250mm (depth) sides are made hollow to insert the 'Z' section inside it. The inner depth of the hollow box section is decided based on the maximum depth of 'Z' section tested. Inside the hollow box a plate is welded from the top without touching the bottom flange near the web face of the 'Z' section to avoid the rotation at loading point. The schematic diagram is shown in Figure 4.

3.2 Test setup

All the tests were conducted in the Test Rig fabricated as described. The loading frame was firmly bolted with 25 mm bolts above the foundation bed. The end gusset angles were welded on the top of the gusset plate. The specimen was firmly fixed inside the angles at end supports by using 2 numbers of 10mm bolts on the web of the 'Z' section at each end. Two roller supports were fixed on the steel box to transmit the load from the jack to the specimen.

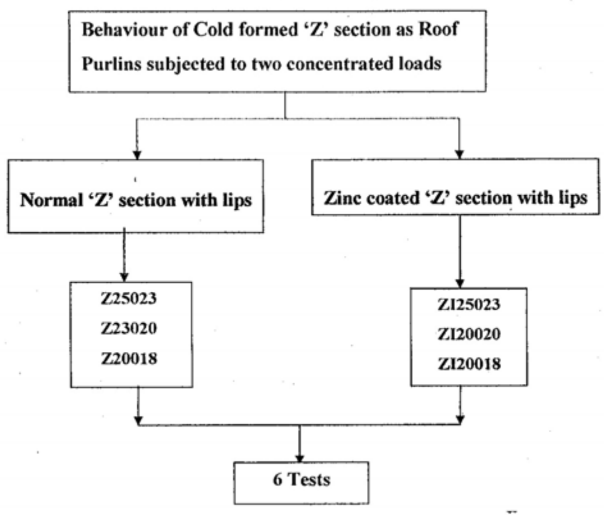

Figure 4: Details of Specimens Tested

Table 1: Properties of Specimens

S.No.	Section	Depth (mm)	Thickness (mm)	Flange (mm)	Lip (mm)	Weight (kg/m)	Ixx (x 10^4 mm^4)
1.	Z25023	250	2.3	80	21	7.85	949.70
2.	Z23020	230	2.0	75	18	6.30	646.53
3.	Z20018	200	1.8	58	16	4.73	357.43
4.	ZI25023	250	2.3	80	21	7.85	949.70
5.	ZI20018	200	1.8	58	16	4.73	357.43
6.	ZI20020	200	2.0	58	16	5.23	394.81

3.3 Testing procedure

The specimens of the 'Z' sections were held in position by means of 2 numbers of 10mm bolt at either ends. Three deflect meters were fixed at the bottom of 'Z' section.

One deflectometer was fixed at the center of the span in 'Z' section. The remaining 2 deflect meters were fixed at 85 cm from either supports. The deflect meter fitted at the bottom of 'Z' section is used to measure the deflection of the specimen under which where the load is applied.

Loading of specimen was done by 50 KN capacity hydraulic jack. Least count of hydraulic jack is 0.2 KN and the least count of deflect meter is 0.01 mm. The loading of specimen was applied gradually by means of placing the jack at the center of loading frame. For each and every increment of loading the corresponding deflections were noted. The loading was applied till the specimen continues to deflect to its maximum limit. The loading is gradually removed to regain the existing shape of the specimen with some amount of residual stress.

4. Results and Discussion

Totally six experiments were conducted on cold formed 'Z' section with lips for bolted end conditions. Only one loading type was applied at two points for each specimen.

4.1 Observed Moment carrying capacity

By using following formula the maximum theoretical bending moment can be calculated.

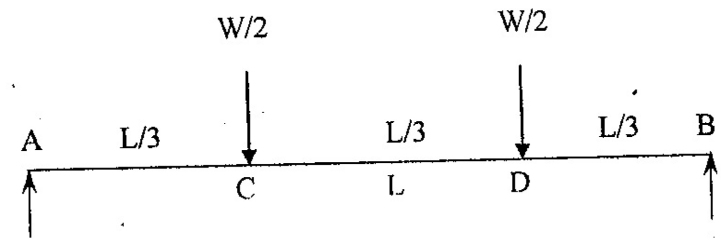

Figure 5: Line Diagram of Position of load

The support reaction at A & B = W/2 KN

The BM at end supports are = 0

The BM at C & D are = W/2 x L/3

The BM at mid span is Mob = W/2 x L/2 - W/2xL/6

The theoretical deflection at C & D

$$= (W/2) \times L^3 / (81\ EI)$$

The theoretical deflection at mid span

$$= (23W/2) \times L^3 / (648EI)$$

4.2 Theoretical moment carrying capacity

The theoretical elastic moment carrying capacity of the section can be calculated as follows:

$$M_{th} = Z_{xx} \times F_y \quad (5)$$

Where, M_{th} = Theoretical elastic moment of the specimen KNm

Z_{xx} = Elastic section modulus in mm_3

$= I_{xx} / D$

I_{xx} = M.I of the section about its major axis in mm^4

D = Overall depth of the section in mm

F_y = Yield stress of the specimen in N/mm^2

4.3 Comparison of Actual with Theoretical values

The comparison of theoretical and observed elastic moment carrying capacities, percentage of variation are presented in the table 2.

Table 2: Comparison of Theoretical and observed Elastic Moment Capacity

Sl. No.	Specimen	Section Modulus (Z_{xx})mm^3	Yield Strength (F_y) N/mm^2	Theoretical Elastic moment (M_{th}) kNm	Observed Elastic moment (M_{ob}) kNm	% age of variation
1	ZI25023	37988	345	13.11	15.77	16.87%
2	ZI20020	19740.5	345	6.81	10.27	33.69%
3	ZI20018	17871.5	345	6.17	7.77	20.59%
4	Z25023	37988	345	13.11	14.47	11.24%
5	Z20020	19740.5	345	6.81	11.27	39.57%
6	Z23020	28110	345	9.70	14.77	34.33%

The above table shows that, the percentage of variation leads to minimum, when the section modulus Z_{xx} of the section is increased. Since, the percentage of variation is inversely proportional with depth of the section. The diagrammatic representation of the comparison of theoretical and observed moment carrying capacities of the specimens.

4.4 Behaviors of charts

Generally all charts are prepared as X-Y plots between the load and corresponding deflection at various stages of the loading specimen. The load is considered in the Y axis and the corresponding deflections are measured in X axis. For the readability of the plot, suitable scale is differently selected for the X and Y axes. Unit length for the X axis is varied based on the maximum values of deflections.

The deflect meters are placed at 0.85m from both supports and the mid span of the test specimen. The deflections at each on-third spans are linearly interpolated from the measured values at 0.85m & 1.0m from either supports almost coincides with each other. But the mid span deflection deviates from the above to the higher degree. Individual color coding and the symbol of notation is used to differentiate various lines.

The figure 6 and 7 shows that, the comparison of load Vs. actual deflections & load Vs. Theoretical deflections at mid span sections for various specimens respectively. Always the actual deflection exceeds with the theoretical deflection. The theoretical deflection almost varies linearly with the corresponding loading condition. Since, the actual deflection deviates towards the plastic stage of the member.

Comparison of actual deflection at mid span section for various specimen results that, the deflection of the specimen is inversely proportional to the depth of the section and the thickness. i.e., the deflection is small for deeper section and vice-versa.

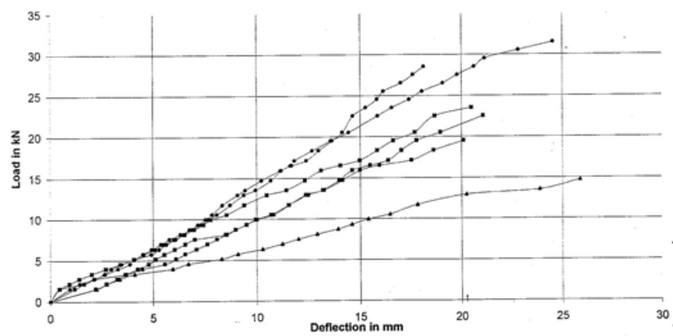

Figure 6: Comparison of Load vs Actual Deflection at Mid Span for Various Specimens

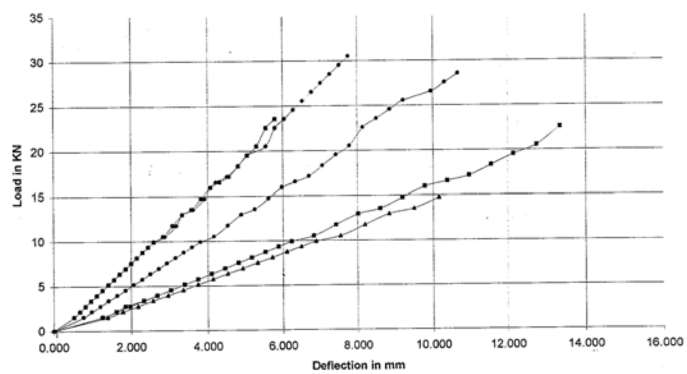

Figure 7: Comparison of Theoretical Deflection at Mid Span for Various Specimens

5. Summary and Conclusion

This investigation aims to study the behavior of cold formed steel ‘Z’ section purlins. Three members of Zinc coated cold formed ‘Z’ sections and three numbers of ordinary cold formed ‘Z’ were tested. The experiments were carried out on a separate test-rig fabricated for this purpose. The specimens were tested under gradually applied two points bending with simple support.

The results obtained from experiments, i.e., the actual deflections, the plastic moment carrying capacities are compared with theoretical values. The load Vs actual deflection for the individual specimen and comparison of actual deflection at mid section for the various specimens were presented as XY charts. The actual and theoretical moment carrying capacities for various specimens are also compared numerically in the tabular form. The following conclusions are arrived at from the present experimental study.

1. The elastic moment carrying capacity is directly proportional to the cross section of the member
2. Due to the partial fixity (50%) of the bolted connections with the end angles at the support, the observed moment carrying capacities are slightly higher than the expected and theoretical values.
3. The percentage of variation between the observed and theoretical moment carrying capacity is minimum, when the depth of the section is minimum. The variation ranges between 11.24 % to 39.57%
4. Comparison of actual deflection at mid span section for various specimen results that, the deflection of the specimen is inversely proportional to the depth of the section and the thickness, i.e., the deflection is small for deeper section and vice versa.
5. There is no much more different between the deflection values for the Zinc coated specimen with the ordinary specimen. Since the zinc coating, effects only with weathering actions not in case of loading capacities.
6. The actual deflection for all the specimens linearly varies with the gradually increased load.

6. References

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