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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

GUIDELINES FOR CARRYING OUT LOAD DEFLECTION TEST OF STEEL PLATE & OPEN WEB AND STEEL-CONCRETE COMPOSITE GIRDERS

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ISSUED BY

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Guidelines for carrying out Load Deflection Test of Steel Plate & Open Web and Steel-Concrete Composite Girders

1.0 Preamble:

Load tests for PSC & RCC bridges are to be done as per provisions mentioned in Para 18 of IRS Concrete Bridge Code, 1997. For load test on Plate, Open Web & Composite Girders, no provisions are available in the IRS codes. Generally load tests are not required in Plate and Open Web Girders, but many times CRS, if considers necessary, orders conducting of load deflection testing of steel bridges also as per provisions mentioned in Para 17 of "The Railways (Opening for Public Carriage of Passengers) Rules- 2000".

The issue of load testing for steel girders was considered under Item 1065 of the 84th BSC held at Goa in November, 2016 wherein it was decided that RDSO should issue detailed guidelines for carrying out load test for steel girders. Subsequently in 85th BSC held at New Delhi in November 2018, the draft guidelines for load testing along with proposed correction slip for amendment to the Railways (Opening for Public Carriage of Passengers) Rules- 2000 were discussed.

This guideline is being issued for the purpose of carrying out load deflection test of Steel Plate & Open Web and Steel-Concrete Composite Girders, if applicable and considered necessary by CRS/CBE or any other competent authority. This guideline is prepared for helping the field engineers. This guideline is just to facilitate and not to supersede any of the provisions of the codes and manuals related to load testing of steel bridge girder over Indian Railways. In case of any difference in this document and any codes and manuals related to load testing of the steel girders over Indian Railways, the provisions in the codes and manuals shall prevail over the provisions of this guideline.

2.0 Applicability of load deflection test:

Load deflection test are normally and also historically not conducted in Steel Plate & Open Web Girder Bridges and Steel-Concrete Composite Girder Bridges. Quality in fabrication & launching is ensured through strict Quality Assurance Procedures, at time of fabrication of Jigs & Fixtures, approval of Welding Procedures, approval of Welders, Inspection of Welding, Trial Assembly of 1st Span, Camber Values under Jacks & without Jacks etc.

The applicability of the load deflection tests in case of steel Plate, Open Web and Composite Girder Bridges will be as follows:

(a) For RDSO standard spans of Steel Plate & Open Web Girder Bridges and Steel-Concrete Composite Girder Bridges, whose fabrication work is also inspected & passed by RDSO officials or RDSO certified fabrication inspection unit under CBE of Zonal Railways or any other third party inspecting agency being engaged with approval of CBE of Zonal Railway, load deflection testing is not required. However, if such type of girder is fabricated first time in Zonal Railway then the load deflection testing may be done to validate the design and drawing.

(b) For non-standard spans of Steel Plate & Open Web Girder Bridges and Steel-Concrete Composite Girder Bridges, if span is being used for the second and/or subsequent time (span already under use in some other bridge over Zonal Railway) and fabrication work is inspected and passed by RDSO officials or RDSO certified fabrication inspection unit under CBE of Zonal Railways or any other third party inspecting agency being engaged with approval of CBE of Zonal Railway, load deflection testing is not required. However, if such type of girder is fabricated first time in Zonal Railway then the load deflection testing shall be done to validate the design and drawing.

(c) Load deflection test on Steel Plate & Open Web Girder Bridges and Steel-Concrete Composite Girder Bridges as described in this guideline, may also be done as a preliminary check on structures where there is doubt regarding serviceability or strength of structure.

However, the applicability of the load deflection test as mentioned in (a) to (c) above is for general guidance purpose. Load deflection test shall be conducted if applicable as per the provisions of applicable codes and manuals in this regard or considered necessary by CRS/CBE/Any other competent authority.

3.0 Test Train/Load for testing:

For load deflection testing, the test train should represent heaviest load which is likely to run in the section. The test train should consist of One/Two locomotives along with sufficient number of evenly loaded wagons with axle loads determined after weighing on a weigh-bridge.

Effort should be there to cover the span fully with wagon load and apply maximum number of axles of wagons on the bridge to generate maximum vertical load on the bridge. Upto 30.5m span generally single loco with 5 loaded wagons is sufficient whereas for 76.2m span double headed loco with 8 loaded Wagons will suffice the purpose.

4.0 Test Speed:

If test train is rolled over the bridge at 5-10 kmph speed (Moving at dead slow speed), results obtained can be taken for static condition. For dynamic tests, test train should be moved at sectional speed. Speed should be noted precisely from speedometer in the locomotive while passing over the bridge.

5.0 Measurement of Deflection:

Deflection can be measured with any of the following methods depending on the suitability of bridge site, accuracy requirement and purpose etc. These methods are explained briefly below:

(a) Card and Recording Pencil Method (Scale System):

Deflection reading is to be taken in the center line of track in mid-span of the Plate Girder or mid-span of OWG. Arrangement should be such that test card is placed at right angle to the center line of track (Arrangement should be independent of the girders of bridge & preferably by use of CC Cribs with vertical arrangement coming out of it) and recording pencil is placed/ tied to bridge, in alignment with center line of track, brushing with the test card. Recording pencil point should be as fine as possible.

(b) Dial Gauge Method:

Dial gauge should rest on independent footing of CC cribs and its plunger should butt with soffit, at mid-span, in the center line of track. Selection of dial gauge should be such that its capacity to record is more than expected deflection & wherein pointer stops at the maximum deflection value. Card & Recording Pencil Method is superior than Dial Gauge Method as it leaves permanent record of measurement, whereas in Dial Gauge skill of BRI/person recording the reading becomes important & also no permanent record is left.

(c) Linear Variable Differential Transformer (LVDT) method:

Deflection of the superstructure can be observed using LVDT (Linear variable differential transformer), by erecting an independent mast on the non-yielding support and with the magnetic base. LVDT having capability of recording displacement up to 1/1000 mm connected with automatic data logger to record in real time. This is one of the most accurate method for recording the deflection of girder on real time with permanent records. However, it is difficult to use LVDT on spans over water, road or with very high clearances.

(d) Laser image deflection measurement:

Laser image deflection measurement is realized by means of the good directionality of laser. The laser fixed on the bridge creates a laser spot on the stationary opto electronic receiver, whose center moves equivalently as the bridge distorts at different levels. Therefore, bridge deflection is available as long as the spot center is obtained. When used on deflection measurement, laser image method is of high-accuracy, which can achieve 0.1mm. Besides, its high sampling rate and low cost are also suitable for bridges of small and medium size.

(e) Deflection measurement of bridge girder using Tort wire:

Mid span deflections of girder, can be measured by installing a tort wire between two adjacent piers or pier and abutment. For this, an invar wire rope is used to prevent changes from temperature. The wire rope is then kept tight with a counter balance, as used for overhead electrical lines of Railways. A non-contact displacement sensor is then used between the wire rope and the underside of the bridge deck. The wire rope is considered the fixed point for reference which will work for normal wind condition.

6.0 Permissible Deflection:

Permissible deflection should be calculated as per following steps:

(A) Note down design EUDL for Bending Moment from Bridge Rules say "X" & corresponding impact factor say "i"

Total LL with impact = $EUDL_{(BM)} + EUDL_{(BM)} \times (i) = X\,(1+ i)$

(B) Note down Dead Load (DL) which is self-weight/weight of fabrication of the bridge (without bearings), from the bridge drawings. Calculate the total Superimposed Dead Load (SIDL) consisting of weight of track structure (Rails, Sleepers & Fittings) acting on complete span.

(C) Note down total design deflection value from bridge drawings (for Open Web Girders total design deflection at mid span is equal to Camber Value provided). Steel is in elastic state & deflection is directly proportional to the load applied. Total design load consists of 4 parts i.e. DL+SIDL+Live Load "X" + Impact Load "X x i" as given in (A) & (B) above.

(D) With total design deflection known and all 4 design loads known as given in (C) above, calculate deflection due to Live Load say "δ_{LL}" & deflection for Impact Load say "δi" (values to be proportionally derived from total deflection value corresponding to the load under consideration w.r.t. Total Design Load). If required, deflection due to DL ("δ_{DL}") and SIDL ("δ_{SIDL}") can also be derived.

Total deflection due to LL = $\delta_{LL+i} = \delta_{LL} + \delta i$

If design deflection values are not available in drawings, then same needs to be got calculated through designer. Same procedure is to be followed in case of non-standard drawings.

(E) Note down precisely axle loads & their spacing in the test train & with help of Software "Clearance of Rolling Stock on Bridges" ***(The Software is available with all Zonal Railways)***, calculate the $EUDL_{(BM)}$ for test train say (X'). Impact for Rolling Speed (5 – 10 kmph) should be taken as "NIL" & for sectional speed impact should be taken as i'

Where $i' = i \times \frac{\text{Sectional Speed}}{125}$.

Test train Live Load without Impact (at rolling speed) = X'

Test train Live Load with impact at sectional speed= X' (1 + i')

(F) Calculate the Permissible Deflection as follows:

Permissible Deflection for Test Train without Impact (at rolling speed) = $\frac{X^F}{X} \times \delta_{LL}$

Permissible Deflection for Test Train at Sectional Speed = $\frac{(1+i^F)}{X\,(1+i)} \times \delta_{LL+i}$

7.0 Example to calculate Permissible Deflection:

To understand para 6.0 an example is given below to find permissible deflection in case of load testing of 30.5 m. span (31.9 m. Effective Span) MBG Standard Loading, welded through type bridge to RDSO Drawing No. BA 11461-11571, with a test train of 2 WDG4 Loco plus 5 BOX'N' Wagons loaded to CC+6+2, running in the section at 75 kmph.

Permissible deflection should be calculated as per following steps:

7.1 Note down design EUDL for Bending Moment from Bridge Rules say "X" & corresponding impact factor say "i"

EUDL for BM for 30 m. = 278.1 tonnes & impact = 0.372

EUDL for BM for 32m = 293 tonnes & impact = 0.361

Derive **X &** $\boldsymbol{i}$ for effective span of 31.9m

X = EUDL for BM for 31.9m = 278.1+ $\frac{14.9}{2} \times 1.9$ = 292.25 tonnes

$\boldsymbol{i}$= Impact factor for 31.9m span = 0.372 - $\frac{0.011}{2} \times 1.9$ = 0.36155

Impact Load = **X x** $\boldsymbol{i}$ = 292.255 x 0.3615 = 105.65 tonnes

Total LL with impact = $EUDL_{(BM)}$ + $EUDL_{(BM)}$ X (i) = **X (1+** $\boldsymbol{i}$**)** = 292.255 x 1.36155

= 397.9197 tonnes

7.2 Note down Dead Load (DL) which is self-weight/weight of fabrication of the bridge (without bearings), from the bridge drawings. Calculate the total superimposed Dead Load (SIDL) consisting of weight of track structure (Rails, Sleepers & Fittings) acting on complete span.

From Drawing BA 11461 available on RDSO rail net Website.

Note Dead Load (Self Wt) from Drawing = **DL** = 55 tonnes.

For SIDL let there be 60 kg main line rail, 52 Kg guard rail & channel sleeper with fittings @ 170 kg/sleeper at 1660 sleepers per KM density i.e. 170 x 1.66 = 282.2kg/m for sleeper & fittings.

SIDL = 60 kg/m + 82kg/m. + 282.2 kg/m. = 394.2kg/m say 400kg/m.

Super imposed Dead Load on bridge = **SIDL** = $\frac{400}{1000} \times 31.9m$

= 12.76 tonnes

7.3 Note down total design deflection value from bridge drawings (for Open Web girder total design deflection at mid span is equal to camber value provided). Steel is in elastic state

& deflection is directly proportional to the load applied. Total design load consists of 4 parts i.e. DL+SIDL+Live Load “X” + Impact Load “X x i” as given in para 8.1 and 8.2 above.

Note from Camber Drawing 11464/R

Max^m Camber Value at Mid Span = Design Deflection = 26.3mm.

This Deflection Value is caused by 4 Loads, calculated in para 8.1 and 8.2 above which is mentioned below:

DL = 55 tonnes (i)

SIDL = 12.76 tonnes (ii)

LL (without impact) = X = 292.255 tonnes (iii)

Impact Load = **X x *i*** = 292.255 x 0.3615 = 105.65 tonnes (iv)

Total Design Load = (i) + (ii) + (iiii) + (iv) = 465.679 tonnes.

Kindly see above 4 Loads causes total deflection/camber value of 26.3mm & proportionate deflection due to each 4 components of load can be calculated on proportionate basis.

7.4 With total design deflection known and all 4 design loads known as given in para 8.3 above, calculate deflection due to Live Load say “δ_{LL}” & deflection for Impact Load say “δi” (values to be proportionally derived from total deflection value corresponding to the load under consideration w.r.t. total Design Load). If required, deflection due to DL (“δ_{DL}”) and SIDL (“δ_{SIDL}”) can also be derived.

Total deflection due to LL = $\delta_{LL+i} = \delta_{LL} + \delta i$

Deflection due to Live Load = $\delta_{LL} = \frac{Live\ Load}{Total\ Load} \times Total\ Deflection$

$= \frac{292.255}{465.679} \times 26.3$ = 16.51mm.

Deflection due to Impact Load $=\delta i = \frac{Impact\ Load}{Total\ Load} \times Total\ Deflection$

$= \frac{105.65}{465.679} \times 26.3$ = 5.97 mm.

Deflection due to Live Load + Impact $=\delta_{LL} + \delta i$ = 16.51 + 5.97

= 22.48 mm

Similarly δ_{DL} & δ_{SIDL} can be calculated.

7.5 Details of Test Train and calculations of Live Load EUDL (BM) from Software "Clearance of Rolling Stock on Bridges" ***(The Software is available with all Zonal Railways)*****:-**

Test train, as mentioned in para 8.0, has been assumed in present case to consist of 2 WDG4 Loco plus 5 BOX'N' wagons loaded to CC+6+2, running in the section at 75 kmph.

Note down precisely Axle Loads & their spacing in the test train & with help of Software "Clearance of Rolling Stock on Bridges", calculate the EUDL(BM) for test train say **(X')**.

Impact for rolling speed (5 – 10 kmph) should be taken as **"NIL"** & for sectional speed impact should be taken as $\mathbf{i}'$where $\mathbf{i}' = \mathbf{x}\ \frac{\textbf{Sectional Speed}}{\textbf{125}}$.

Test train Live Load without Impact (at rolling speed) = X' = 277.6 tonnes.

Test train Live Load without Impact $i' = i \times \frac{\text{Sectional Speed}}{125} = 0.3615 \times \frac{75}{125}$

= 0.2169

Test train Live Load with impact at sectional speed= X' (1 + i')

= 277.6 x1.2169

= 337.81 tonnes.

7.6 Calculate the permissible deflection as follows:

Permissible deflection for test train without Impact (at rolling speed) = $\frac{X^F}{X} \times \delta_{LL}$

$$= \frac{277.6}{292.255} \times 16.51$$

$$= 15.68\text{mm}$$

Permissible deflection for test train at sectional speed = $\frac{(1+i^F)}{X\,(1+i)} \times \delta_{LL+i}$

$$= \frac{277.6 \times 1.2169}{292.255 \times 1.3615} \times 22.473$$

$$= 19.08\text{mm.}$$

8.0 Drawing of Conclusion from Load Deflection Test:

Normally deflection recorded should be less than the permissible deflection calculated above. Reason for lesser deflection recorded is that steel structures have sufficient residual strength beyond elastic limit and, in many structures, alternate load paths are available and whenever load on structure exceeds the elastic limit of some part, the same might not fully reflect in the deflection. Secondly due to simplifying assumptions such as pin-jointed trusses, zero fixity at ends, ignoring the effect of track continuity and 2-D behavior of girders, the actual deflection of the structure is often lower than the theoretical deflection computed.

In case, if deflection recorded is less than permissible deflection given in para 7.6 above, then bridge can be said to be in satisfactory condition.

In case, if deflection recorded exceeds the permissible deflection, but sum of recorded deflection plus theoretical deflection due to DL+SIDL is less than $\frac{L}{600}$, then bridge is safe from operations point of view but reasons for variations should be ascertained.

In case, if sum of recorded deflection plus theoretical deflection due to DL+SIDL exceeds $\frac{L}{600}$, then something is wrong and further detailed investigation of Bridge by instrumentation or other suitable methods needs to be carried out.

It is important to understand that sometimes under Dead Loads, the deflection value may be found abnormal. The possible reasons for abnormal values under Dead Load are deformation/drooping of flanges during welding of plate girders, local deformation of members during launching, creep & shrinkage effect of concrete in deck slab of composite bridge etc. These factors may be kept in mind while evaluating the absolute value of deformation. In load test, the differences of Initial deflection and the final deflection i.e. the deflection under Live Loads shall be the important parameter to decide the performance of the Girder.

9.0 Load Deflection Test of Steel-Concrete Composite Girders:

In Composite Girders due to composite bending action, tensile stresses are generated in bottom steel flange & compressive forces are generated in concrete deck slab. The shear connectors play the decisive role in composite action of the Composite Girder. Being hidden item, inspection of shear connectors is not possible from outside. The Load Deflection Test of Composite Girders should be done as per provisions mentioned in Para 18 of IRS Concrete Bridge Code, 1997.

9.1 As per stipulations of clause 18.2.3 of IRS Concrete Bridge Code, test loads are prescribed for two limit states i.e. (a) Limit states of deflection and local damage, (b) Ultimate limit state.

9.2 In case of limit state of deflection and local damage, test loads to be applied are characteristic* dead and imposed loads. There is no requirement of maintaining test loads for 24 hours in this limit state.

9.3 In case of ultimate limit state, test loads should be equal to sum of characteristic* dead load plus 1.25 times the characteristic* imposed loads. There is requirement of maintaining test loads for a period of 24 hours in this limit state.

9.4 Load testing as per ultimate limit state mentioned in clause 18.2.3 of IRS Concrete Bridge Code and/ or compressive strength tests of concrete (Core Test) may be done in case of doubt regarding the grade of concrete used, either due to poor workmanship or based on results of cube strength tests. However, in cases, the core test results do not satisfy the requirements of clause 17.4.3 of IS 456: 2000 or where such tests have not been done, then Load test as per ultimate limit state mentioned in clause 18.2.3 of IRS Concrete Bridge Code may be resorted to.**

9.5 Load testing whether in limit state of deflection or Ultimate limit state as stipulated in clause 18.2.3 of IRS Concrete Bridge Code, generally measure the elastic response of the bridge superstructure. The levels of loading necessary should be such that they are sufficient to obtain measurable responses from the structure without causing any permanent damage to structure. So necessary calculations should be done before commencement of load testing to ensure that structure is in elastic range after the application of test loads.

*Clause 11.1 of IRS Concrete Bridge Code stipulates that values of loads as given in IRS Bridge Rules shall be taken as characteristic loads.
**Refer clause 17.3, 17.4, 17.5 and 17.6 of IS 456:2000. "

10.0 Limitations of load deflection test:

The various limitations associated with load deflection test are in case of steel girders are given below:

(i) Steel is a perfect elastic & homogeneous material produced under strict quality control over its chemical composition, physical & mechanical properties in factory premises. The properties including ductility of steel as a building material are normally beyond any doubt. The problems associated with fabrication, which are often sought to be verified through load deflection tests, come into play only after repeated application of loads (Fatigue Loading). One time application of load in load deflection test is not the right tool for verifying the quality of fabrication.

(ii) Establishing independent reference to measure the deflection using dial gauge or scale system is not possible at all locations and this means that the shore spans where height is less and water not present are the often default choice for carrying out the load test. This reduces the efficacy of load test.

(iii) Steel structures have sufficient residual strength beyond elastic limit and, in many structures, alternate load paths are available. Even if load on structure exceeds the elastic limit of some part, the same might not fully reflect in the deflection. Due to simplifying assumptions such as pin-jointed trusses, zero fixity at ends, ignoring the effect of track continuity and 2-D behavior of girders, the theoretical deflection computed is often higher than actual deflection of the structure. Comparing the actual field measurements of static load test with theoretical computations often lead to erroneous conclusions.

(iv) For long span bridges, dead load and superimposed dead load itself is a substantial component of the entire load carrying capacity. In this scenario, live load component might not be significant for the overall girder (Though it is still important for some individual components). For such girders, the camber values immediately after launching and after providing superimposed dead load might give good idea of the behavior of structure.

(v) The impact factor given in codes is a statistical value, which depends on several factors such as condition of track, condition of vehicles, dynamic rail wheel interaction and operation characteristics etc. which are difficult to create/replicate in field. The error due to unknown impact factor might make the deflection reading difficult to interpret.

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