# SEISMIC EVALUATION AND RETROFITTING OF RCC SKEW BRIDGE PIER USING RCC JACKETING

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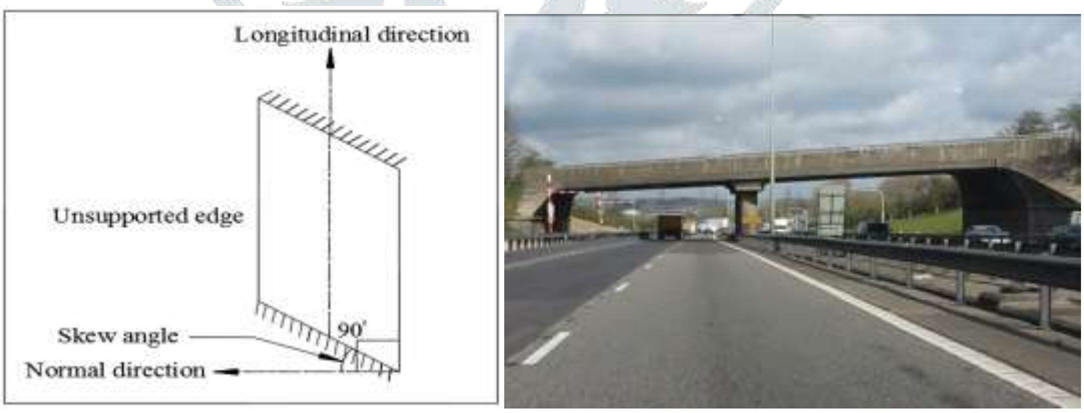
***Abstract :*** ***RCC skew bridges are more often encountered in the highways. Recent growth of transportation infrastructure has increased the number of skew bridges in India. In this paper the RCC skew bridge with skew angle $60^0$ is taken into consideration and its analysis is done using the finite analysis software. The bridge is subjected to dead loads, IRC standard moving loads and also response spectrum analysis is done to take into account the earthquake effects. The behavior skew bridge is observed in terms of bending moments, shear force and torsional moments and then the design of pier is done. The RCC bridges undergo the deterioration over the period of time and there after it may not be able to withstand the given stress. Deterioration causes loss of strength and alternatively in moment of inertia of RCC members. This effect can be taken into account by effective moment of inertia concept specified in various codes. It is necessary to retrofit the piers. The paper implements Indian code IS 15988-2003 to retrofit the RCC bridge pier taken into account for this study. After jacketing the pier shows satisfactory results for the given loads. In this paper two span RCC T girder skew bridge is analysed for its forces. Pier are considered as a subject of study and its modelling as degraded structure and check for safety for current critical load combination is taken. Form the results it is found that pier needs retrofitting so it is done with the method of RCC jacketing and again it is checked for structural strength criteria and serviceability criteria. RCC jacket have improved its flexural capacity, shear capacity and also made bridge safe in strength and serviceability.***

***IndexTerms - skew bridge, response spectrum, effective moment of inertia, IRC, Jacketing, cracked section.***

## I. INTRODUCTION

Structure which facilitates the passage over an obstacle without closing the way below it is called as the bridge. The bridges are very important structures for country facilitating transportation and thereby contributing to economic industrial growth of the country. The RCC T girder bridges are most commonly used in the highways generally for the span of 10 m to 25 m. The main longitudinal girders forms a T beam with the deck which is cast monolithically. So the bridge is designed and called as T girder Bridge. Simply supported T girder bridges become uneconomical over the span of 30 m.

Increased rate of urbanization the need for complex transportation systems is also increased. That leads us to the complex shaped bridge geometries. Skew bridges are the perfect example of such complex geometry which is result of complex intersections, geometric restrictions, rough topography or limitation or space for right bridge. In spite of being structurally very much different the analysis and design of skew bridges is not very much changed. A bridge built at right angle to the abutment or pier cap is called as right bridge and bridge built obliquely to the abutments is called as skew bridge. Skew angle is an angle between normal to the centre line of the bridge and the centre line of the piers.




(a) (b)

Figure 1. (a)Skew bridge sketch (b) Photo of skew bridge

There are various types of skew bridges depending on the orientation of cross girders viz. skewed cross girder type, fanned cross girder type, trimmed cross girder type. For this study the skewed cross girder type bridged is taken. Type tobe used is basically depends on the structural demand and construction technology available.

In past literature about seismic analysis of bridge piers, Omkar velhal and J. P. Patankar have studied the behaviour of simply supported RCC T girder bridge with single span. The focus of study was to understand effect of skew angle on the bridge. The research showed the variation of structural parameters like bending moment, shear force and twisting moment with respect to the change in the skew angle. Amount of twisting moments and shear forces is significantly increased in bridges girders and in columns as the skew angle increased from $0^0$ to $60^0$ and also considerable decrease in bending moments for the same. This study showed us the most critical skew angle is $60^0$.

The modelling of damaged structures is one of the major challenges in the field of finite element analysis. Now various codes have simplified the process with the help of cracked section analysis. Cracking reduces the flexural and shear strength of any RCC structural member. Researchers like Barnson and Yu have studies the same effect and given the empirical formulae. Considering its major advantage the various codes like Euro code, IS codes and New Zealand codes included this cracked section analysis after various corrections applied to the Barnson formulae.

Many of the RCC bridges have built in 1970 to1990 are now have various structural defects such as cracks due to environmental factors and some seismic events. Therefore various retrofitting technologies have emerged as the solution. The steel and RCC jacketing are the major technologies that contributed a lot in the retrofitting due to its advantages like economy, ease in construction and its effectiveness in seismic and wind loads.

Recent accidents in India have shown great need to inspect and retrofit many of RCC bridges. For the same purpose the method of RCC jacketing is very much useful and also widely used in the practice for many buildings. Jacketing is the process by which the existing structural member is restored to its original dimension or increased in the size by encasement with the help of suitable materials like concrete or steel or FRP. For the RCC members the most suitable method is RCC jacketing as we can easily perform it on field and it is economical with respect to other methods present for RCC members. One of the major advantage of RCC jacketing is that it can make perfect bonding between old and new surface. This is due to concrete can be easily casted in situ in any shape and size.

Figure 2. RCC jacketing of piers

In another research article by Gupta et al. step by step procedure of retrofitting of RCC columns as per Indian standard is given. The seismic demand of columns in terms of axial load and moments is calculated. The section size and amount of reinforcement is estimated. Then current size is deducted from the demands. Final areas for jacketing are calculated using various clauses regarding jacketing and application of them in earthquake damaged columns have been shown in the research paper.

## II. Problem Statement

Considering the general span length for skew RCC T girder bridges and number of spans we generally come across in the real life following problem statement is considered. The angle of skew is assumed such that it gives the maximum twisting effect and maximum shear force on the girders and alternatively on pier. Single column bent is considered as it is very much present in the bridges which require the retrofitting now a days. The loading considered on the bridge and the load combinations taken into account are taken from IRC 6. Apart from that the standard dead loads taken for various members as specified follows. Analysis is done using the MIDAS (civil) which is very much used in finite element analysis of bridges.

a) Clear width of roadway is =7.5m, Total width including parapets = 8.7m
b) Span L=16m, No. of spans considered=2 (span is adopted considering RCC T girders are used upto spans of 25m as it is practically economical )
c) 3 main T girders are at 2.5 m c/c interval
d) Depth of deck slab is 200 mm
e) wearing coat thickness is 60 mm
f) Kerbs are 600 mm in width and 300 mm in height
g) Depth of main girders and cross girders is kept 1600 mm as per thumb rule of 10 cm per m span
h) Width of main and cross girders is taken as 300 mm
i) Cross girders are provided perpendicular to main girders @ 4m c/c
j) Skew Angle kept is $60^0$ to maximize skew effect
k) height of pier = 7.5 m

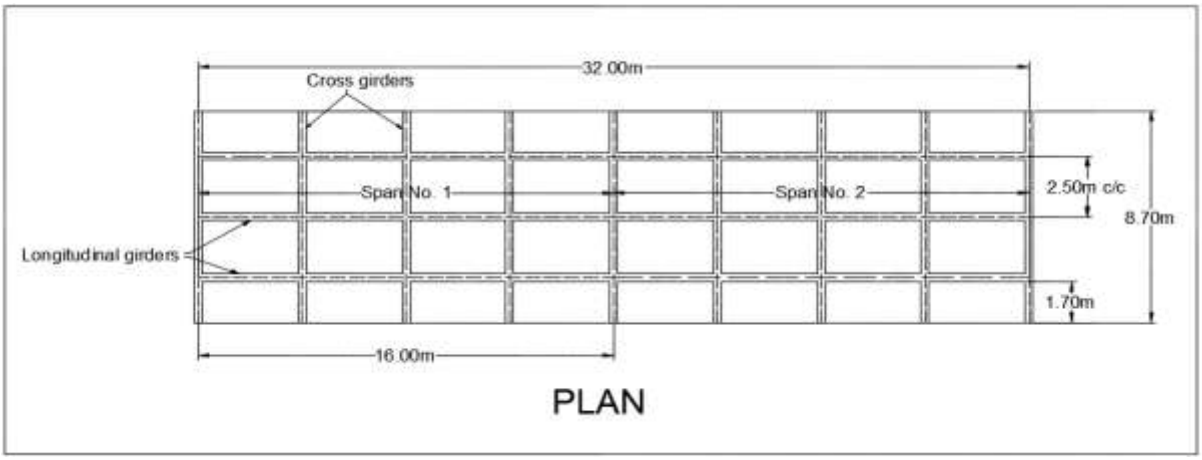



Figure 3.Plan of two span RCC T girder bridge.

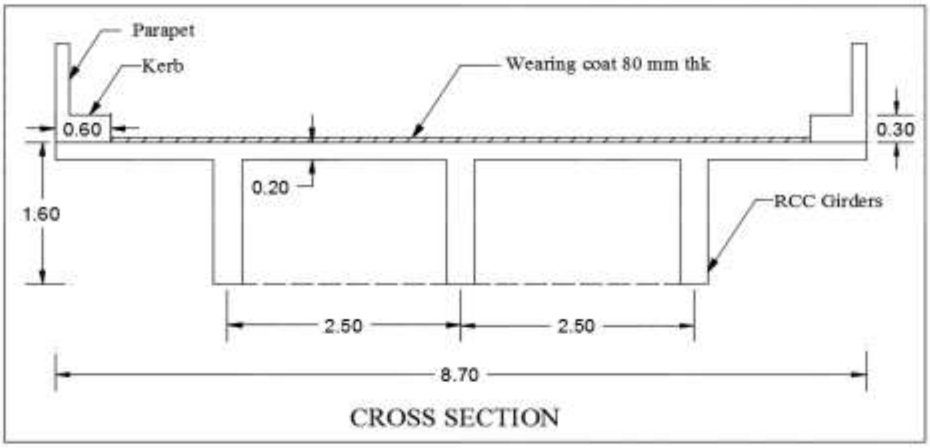



Figure 4.Cross-section two span RCC T girder bridge.

## III. Loading

A) Dead Load

Loading considered on the bridge site is as follows

*a)* dead load of structural members like T girders, piers, pier caps, deck slab

*b)* dead load of non-structural members like wearing coat, kerbs, parapet

B) Moving Load

Moving loads are one of major type of loads in case of bridges. The loads that have been considered for this study are according to IRC 6. Now in our case, we do have 2 lane bridge. Clear roadway width taken for this problem is 7.5 m therefore according to IRC 6 following two load cases are specified. Moving loads consist of two combinations; first is with one vehicle of IRC standard class 70R load tracked vehicle from eccentricity of 'c' and another combination consist of two vehicles of IRC standard Class A loading as specified in the IRC 6.

C) Earthquake loading

Earthquakes are natural occurring phenomenon and the effect of earthquake is primarily function of weight of structures which is huge. There are several types of analysis performed on bridges to get quake effect as follows. The loading as per IS 1893-2014 Criteria for Earthquake resistance design of Structures; part III Bridges and Retaining Walls. This code specifies following different analysis procedures.

a. Linear static procedures: Equivalent static analysis

b. Linear dynamic procedures :Modal analysis , Response spectrum analysis

c. Nonlinear static procedures :Pushover analysis

d. Nonlinear dynamic procedures :Time history analysis

For this study Response spectrum analysis is performed. Parameters used in this study are as follows.

The seismic zone considered is fifth and highest, T girder bridges are small span bridges and they do have alternative routes. As our bridge is old we have considered that it do not have ductile detailing in its pier. Soft soil foundation condition is taken for study.

Table 1.Seismic Parameters

| Sr. No. | Parameter | Values |
|---|---|---|
| 1 | Zone factor | 0.36 |
| 2 | Importance factor | 1 |
| 3 | Response reduction factor | 2.5 |
| 4 | Soil type | III |

## IV. Modelling

For the present study, finite element analysis software MIDAS Civil is used which provides sophisticated approach towards bridge modelling. It provides detailed results with various load combinations with various structural diagrams and contours.

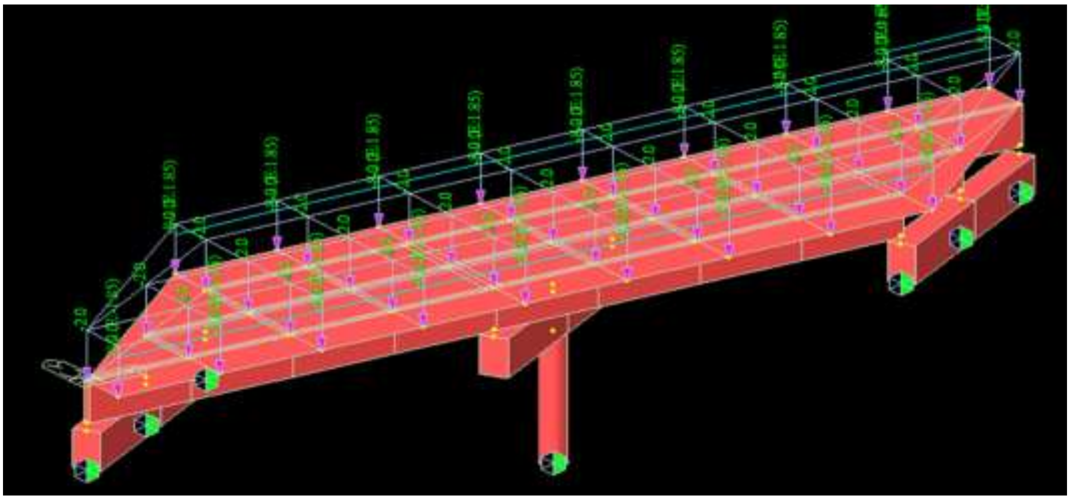


Figure 5.MIDAS civil model of skew bridge

Load combinations used in this model are taken from IRC 6. From the head of load combinations for structural strength for getting bending moment and shear force. Deflection vibration are covered into separate serviceability criteria. From the analysis done following data is obtained for various structural members.

Table 2.Maximum forces in various structural members

| Sr. No. | Structural member | Type of Force | Value |
|---|---|---|---|
| 1 | Internal T girder | Bending moment | 1228.6 kNm |
| 2 | Internal T girder | Shear force | 556.5 kN |
| 3 | Internal T girder | Twisting moment | 167.2kNm |
| 4 | External T girder | Bending moment | 1940.2 kNm |
| 5 | External T girder | Shear force | 753.5 kN |
| 6 | External T girder | Twisting moment | 321.6 kNm |

## V. Design of RCC Pier

Design of pier of bridge is done using the IRC 112-2011 Code of Practice for Concrete Road Bridges. Design forces for pier were as follows.

Table 3.Design parameters for bridge pier

| Sr. No. | Design parameters | Values |
|---|---|---|
| 1 | Axial load | 7437.8 kN |
| 2 | Bending moment in x direction | 3038.7 kNm |
| 3 | Bending moment in Y direction | 1454.7 kNm |
| 4 | Height of pier | 7.5m |
| 5 | Diameter of column | 1m |
| 6 | Characteristic strength of concrete | 30 N/mm$^2$ |
| 7 | Yield strength of steel | 500 N/mm$^2$ |
| 8 | Effective length of pier | 1.3 X 7.5 = 9.75 m |
| 9 | Slenderness ratio | 9.75/1 = 9.75 < 12….short column |
| 10 | Eccentricity check | 9750/500 + 1000/30 = 48.83 < 0.05 D |

From the above parameters, design obtained form IRC 112-2011 for bridge pier is as follows.

1. Diameter of pier = 1000mm
2. Area of compression steel = 17690 mm$^2$
3. Lateral ties = 10 mm # @ 200 mm c/c

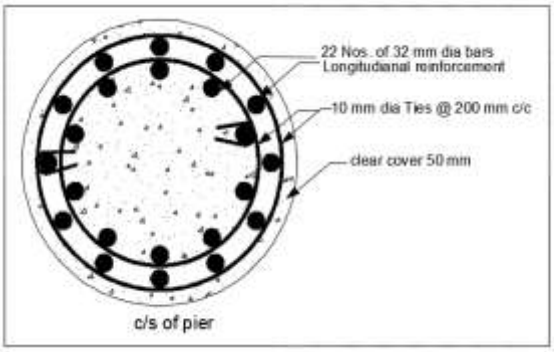



Figure 6.Corss-Section details of bridge pier

## VI. Modelling of Degraded Pier

One of the challenges in FEM modelling of structures is to model old structures which have defects like cracks in concrete, corrosion of steel. This problem was firstly tackled by scientist Barnson. He gave solution in terms of effective moment of inertia. This equation is widely used in calculation of actual strength of various structural members for RCC structures. Later various correction are added to it by scientist like YU and Winter and after that the codes specified its values as modified EI (flexural stiffness).

Indian code specified the effective values of EI for column is as follows.

Flexural rigidity

a. $0.7E_cI_g$ - for column in compression ($P<0.5f_c'A_g$)
b. $0.5\ E_cI_g$ - for column in compression ($P>0.5f_c'A_g$)

Shear rigidity reduces to $0.4E_cA_w$ and axial rigidity has no change in it. Above mentioned values are used to calculate reduced section size of a pier.

Using IRC 112-2011 and IS 1893-2014 we have calculated the strength and checked the safety of degraded pier.

$I_{eff} = 0.7$ Ig

Now modelling purpose Dia. Of pier is reduced to D = 910 mm (i.e. Ie)

check for moment carrying capacity

Puz = 0.45fckAc + 0.75fyAsc

= 0.45x30x757151 + 0.75 X 500 X 28247

Puz = 27628 kN

$(M_{ux1} / M_{ux})^{\alpha} + (M_{uy1} / M_{uy})^{\alpha} < 1$ (by IRC112-2011)

$= (30389.7/2486.78)^2+(1454.7/2486.78)^2$

= 0.3421 + 1.49 > 1

This has showed us that degraded model is safe in axial compression but not safe in biaxial bending. That implies the bridge pier needs retrofitting.

## VII. Retrofitting of Degraded Pier

Retrofitting is a method to stop the degradation and restore original strength of member. Jacketing is the process whereby a section of an existing structural member is restored to original dimensions or increased in size by encasement using suitable materials.Jacketing is particularly used for the repair of deteriorated columns, piers, and piles and may easily be employed in underwater applications. Before applying jackets or collars, all deteriorated concrete must be removed, cracks must be repaired, existing reinforcement must be cleaned, and surfaces must be prepared. A drawback of jackets and collars is that they occupy space that was earlier available for other uses. RCC jacketing for columns under seismic load guidelines are given in the IS 15988 2013 and IS 13935-1993.

A. Design of RCC jacket

Pu = 7450 KN  Mux = 3038.7 kNm  Muy = 1454.7 kNm

Dia of column required for above demand is 1000 mm

Ag(1000mm) = 785398 $mm^2$

Now actual dia available = 910 mm

$A_{g(910mm)} = 650388\ mm^2$

Ag of Jacketing = (785398 – 650388)

Ac' = 135009 $mm^2$

ie Dia of column required = 3/2 Ac'

$1.5 \times 135009 = \Pi/4 \times D^2 - \Pi/4 \times 910^2$

Dreq = 1042.08 mm

Min 100 mm jacketing should be done

$D_{pro}$ = 910+100+100=1110 mm

$Ac_{pro} = 967689\ mm^2$

provide minimum reinforcement of 0.08Ag

Asc = 2538.40 $mm^2$

provide 10 bars of 20 mm dia as longitudinal reinforcement

Ties of 10 mm dia

spacing (s) = $fy/(fck)^{1/2} \times Dh^2/tj$

$= 500/(30)^{1/2} \times 10^2/100$

= 91.28 mm

provide 10 mm dia ties @ 90 mm c/c

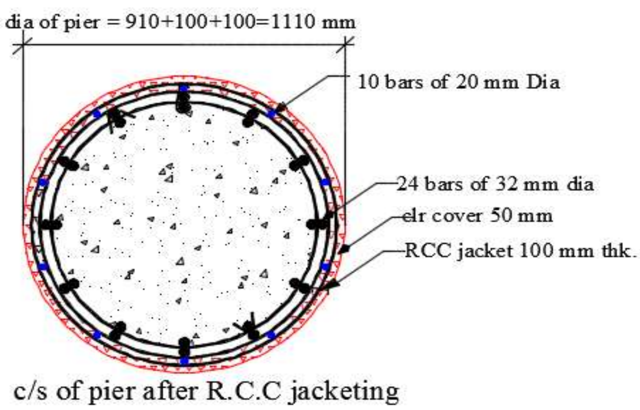



Figure 6.Corss-Section details of retrofitted bridge pier

Hence we have restored flexural strength with the help of RCC jacketing and structural strength criteria for RCC T girder bridge is now once again satisfied. Now for the serviceability criteria once again model of Retrofitted bridge is prepared in MIDAS civil and deflection check is taken. Maximum deflection we obtained on the deck is 27.33 mm which is well below specified limits by IRC 112-2011.

## VIII. CONCLUSION

Twisting moments plays important role in case of Skew Bridge design along with bending moments and shear forces. The Maximum values of bending moments from critical load combination decreases with increase in skew angle and maximum values of twisting moments increase with increase in skew angle and this behaviour is shown upto skew angle reaches to $60^0$.

Piers of old RCC bridges lacks ductile detailing and therefore those are more susceptible to damage due to earthquake loads. Damage consists of cracking of concrete and loss in flexural and shear capacities and hence need of retrofitting of piers is generated. This degradation can be easily modelled in FEM software by using concept of effective moment of inertia by use of various codes.

RCC jacketing is simple, economical and easy way to restore the flexural capacity of RCC bridge piers and it can be easily applied to any RCC piers. Results showed that retrofitting of bridge pier by RCC jacketing is efficient and it has restored flexural capacity enhanced axial load carrying capacity and bridge becomes safe in structural strength criteria and also serviceability criteria.

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