PARAMETRIC STUDY ON SKEW UNDERPASS BRIDGE

1V RAGHAVA KUMAR, 2R.KINGLE

1M.Tech. Student, Department of Applied Mechanics, VNIT, Nagpur, India
2Professor, Department of Applied Mechanics, VNIT, Nagpur, India
E-mail: 1vanama.raghavakumar@gmail.com, 2rkingle@rediffmail.com

Abstract—Overhead catenary wires and high level embankments of railways make Railway Over Bridge (ROB) to occupy more space in order to maintain the adequate gradients on the access ramps. Pushing a Precast-concrete box structure using jacks is a preferable solution at such situations. Thus the vehicular traffic is allowed inside the box structure whereas rail traffic goes over the box. Often, construction details call for skew box with railway lines above the box structure that are not necessarily perpendicular to the roadway of the bridge. In design practice, these underpass skew bridge structures are typically analysed as simplified two-dimensional frames. However three dimensional finite element analysis controls the behaviour of skewed structures that a plane frame analysis cannot represent. This paper explains the structural performance of box structure of underpass bridge with varying skew angle, geometric parameters, influence of soil structure interaction and effect of haunch. To understand the behaviour, series of Finite Element Analysis (FEA) were performed using SAP2000 on a number of skew box (skew angles varies from 0° to 60°) underpasses to simulate various geometric configuration parameters. Based on the FEA results, series of correlation diagrams were developed relating the moments and deflections due to dead loads in a skew underpass to those from plane frame analysis considering unit width for analysis.

Index Terms—Underpass skew bridge, Three-dimensional Finite element analysis, Soil-structure interaction, Haunches.

I. INTRODUCTION

Most of the investigations were on simply supported skewed girder bridges (ROB) and on skew bridges with integral abutment walls. Fewer studies were presented on the structural behaviour of box structure of Underpass bridges which came in recent times. So there is a lot of scope in investigation of box structure of Underpass skew bridges. This study compares the plane frame analysis with three-dimensional finite-element analysis. Also three-dimensional finite-element geometrical parametric underpass bridge models were analysed considering soil structure interaction to identify its critical responses. Later the study is extended to find the effect of haunches on structural behaviour of skewed railway underpass box structures are performed [1]. A series of FEA on a number of skew bridges with integral abutment walls to simulate various geometric configuration parameters as well as laterally symmetrical and unsymmetrical vertical loading conditions. This study included higher aspect ratios than considered by previous researchers and produced a series of comparison design charts for the skew effects. The effect of haunches on the skewed, three-sided, precast-concrete structures using a preliminary three-dimensional FEA is also incorporated [2]. The statistical analysis of the results given [3] showed that among various parameters, the width had the greatest effect on the maximum positive moment stresses, whereas the span, width and skew angle had the greatest effect on the minimum negative moment stresses. A linear elastic FEA conducted [4],[5] to verify the effects of dead loads, AASHTO live loads, and earth pressures on 20 different bridges. Based on the FEA results, they developed a series of design charts relating the moments, shears, and deflections in a skew bridge to those in a 0.33 m wide plane frame section.

In this paper, an analytical study was carried out for the structural performance assessment of precast concrete box girder of underpass skewed bridge. Typically, these structures are designed as simplified two-dimensional frames (Fr), neglecting the effects of the skew angle which is not appropriate model for such situation. To evaluate the limitations of this practice, three-dimensional finite element models (FE) were developed and analysed. The results of the simplified plane frame analyses and three-dimensional finite-element analyses were presented in correlation diagrams, enabling simple comparison and quantification. The response observations offer a qualitative insight into the actual behaviour of the structure, allowing the performance assessment of existing bridges of the same type and a more reliable design in the future. Accordingly, these finite-element models simulate various geometric configuration parameters with varying skew considering the influence of soil structure interaction and haunch configurations capturing the amplification of the structural response.

The solid model of the underpass bridge with the relevant configuration parameters defined in the finite-element analysis of this study is shown in Fig. 1.

Fig. 1 Parametric solid model of an Underpass skew bridge
II. CONFIGURATION PARAMETERS FOR THE PARAMETRIC BRIDGE MODELS

Series of FEA have been performed on a number of skewed box underpasses to simulate various geometric configuration parameters as shown in I.

I. Geometric configuration parameters and their dimensions

<table>
<thead>
<tr>
<th>Configuration parameter</th>
<th>Discrete Dimension modelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span length (L)</td>
<td>3.75 m, 7.5 m, 10.5 m</td>
</tr>
<tr>
<td>Height (H)</td>
<td>3.5 m, 5.5 m</td>
</tr>
<tr>
<td>Width (B)</td>
<td>1 m, 11.85 m</td>
</tr>
<tr>
<td>Thickness (t)</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Skew angle</td>
<td>0°, 15°, 30°, 45°, 60°</td>
</tr>
</tbody>
</table>

III. MODELLING

Firstly box structure of underpass bridge was modelled as a typical frame element and then finite element modelling was done in SAP2000. In Frame model the bottom frame is divided into number of frame elements and hinges are assigned at each node as shown in Fig. 2. Similarly in finite element analysis, the bottom area element is meshed into smaller areas and then hinges are assigned at each node as shown in Fig. 3. Later hinges are replaced by soil springs. In FE modelling, thick shell element has been used as area element to configure reinforced concrete element.

Material properties assigned for the reinforced-concrete elements of the frame and finite element models are M40 grade concrete having modulus of elasticity $E_C = 3.162E+7$ kN/m$^2$ with Poisson’s ratio as 0.2. Unit weight of reinforced concrete is considered as 25 kN/m$^3$.

IV. ANALYSIS RESULTS

Parametric study on skew underpass is performed for various parameters such as, soil stiffness, span length, width, height, haunches and skew angle starting with FE vs. Fr analysis and these results are presented below.

A. Finite Element (FE) vs. Frame (Fr) analysis with Hinge boundary condition

Underpass skew bridge of height 3.5 m and span length 7 m having unit width is considered for the analysis. Based on the FEA results, series of correlation diagrams were developed relating the moments and deflections due to dead loads in a skew underpass to those in unit width plane frame section. Correlation diagrams relating the moments and deflections due to dead loads are shown in Fig. 4 and Fig. 5 for an underpass skew bridge of height 3.5 m and span length 7 m having unit width.

From Fig. 4, it can be observed that both positive and negative moments were considerably higher than moments given by the plane frame analysis. The deflections are comparable up to 30$°$ skew box.

B. EFFECT OF SOIL STIFFNESS

Effect of soil stiffness has been verified using finite element analysis for an underpass skew bridge of height 3.5 m and span length 7 m having unit width. In which, hinges at each node of the bottom slab are replaced by soil springs as shown in Fig. 6.
Stiffness of the each soil spring is calculated by multiplying soil subgrade reaction to area of the element. Four soil subgrade reactions ($K_S$) are taken viz., 22.5 MN/m$^3$, 75 MN/m$^3$, 125 MN/m$^3$ and 250 MN/m$^3$. Variation of moments due to dead loads with varying soil stiffness and varying skew are shown in Fig. 7(a) and (b).

It can be seen from Fig. 8(a) and (b) that span length had greater effect on minimum negative moment. Also it shows an obvious fact that for unchanged boundary conditions moments increases with higher spans. But they follow the same variation for varying skew angle. From Fig. 8(c), it can be observed that skew angle has greater effect on deflections of an underpass bridge with larger span lengths.

**D. Effect of Width**

Firstly, finite element analysis has been performed on an underpass bridge of height 3.5 m, span length 7 m having unit width. Later analysis is extended to 11.85 m width thereby counting the effect of width as shown in Fig. 9.

Variation of moments and deflections due to dead loads with varying span length and varying skew are shown in Fig. 10 (a), (b) and (c) respectively.
From Fig. 10 (a), (b) and (c), it can be seen that width has its effect on moments and deflections only for underpass bridges having skew angle greater than 30°.

**E. Effect of Haunches**

In general, box structures are provided with haunches forming a rigid action at the joints. To evaluate the effect of haunches, finite element analysis has been carried out for an underpass bridge of 7 m span length having 3.5 m of height with 11.85 m width. Models used for the finite element analysis are presented in Fig. 11.

With varying skew angle, variation of Principal maximum, minimum moments and deflections due to dead loads with and without haunches are shown in Fig. 12 (a), (b) and (c) respectively.

As the finite size joint formed by haunch acts partially rigid, maximum positive moment and deflections are found to be lesser by introduction of haunches from Fig. 12 (a) and (c). Fig. 12 (b) shows that there is no variation in minimum negative moment with and without haunches.

**F. Effect of Skew angle**

With increase in skew angle, as shown in Fig. 13, it’s necessary to increase the skew length of the underpass to maintain the same span to end abutment length.

Skew length is calculated as (Length /Cos α) and increase in skew lengths is as shown in II.

<table>
<thead>
<tr>
<th>Skew (deg)</th>
<th>Skew Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.85</td>
</tr>
<tr>
<td>15</td>
<td>12.27</td>
</tr>
<tr>
<td>30</td>
<td>13.68</td>
</tr>
<tr>
<td>45</td>
<td>16.76</td>
</tr>
<tr>
<td>60</td>
<td>23.70</td>
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</table>

The effect of skew angle on moments and deflection can be seen in Fig. 14(a) and (b)
Parametric Study On Skew Underpass Bridge

**Effect of Height**
Effect of height has been verified using finite element analysis for an underpass bridge of span length 7 m having unit width for 3.5 m and 5.5 m heights. Models are as shown in Fig. 15.

With varying skew angle, variation of principal maximum and minimum moments due to dead load for varying heights is shown in Fig. 16 (a) and (b) respectively.

**CONCLUSIONS**

Based on above study, follow conclusions can be summarised.

1. Considering the significant increase in moment values from the FEA over those from the plane frame analysis, two-dimensional analysis of this structure for design purposes is not adequate.
2. The analysis results showed that among various parameters, span and skew angle had the greatest effect on the minimum negative moment and deflection.
3. Width has its effect on moments and deflections only for underpass bridges having skew angle greater than 30°.
4. Soil subgrade reaction and height had not much effect on moments.

In general it is recommended to use FEA for analysis of skew underpass bridges.

**REFERENCES**