

STEEL ARCH BRIDGES FOR AN URBAN OVERPASS

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SUMMARY

Flyovers are routine solutions for over-pass bridges which relieve existing route crossings in urban areas, from excessive traffic burden. Moalem Square, in center of Semnan city, I.R of Iran, is newly replaced by such a bridge to solve growing traffic problem. In design of this flyover a novel and innovative application of arch bridges is utilized. The Moalem Bridge has two main parts i.e. the central and side ramp parts. Central part is a 66 m complete arch steel span and two 24 m half arches. Side parts; contain several 18m and 15m continuous girder spans. Several detail design and analyses such as moving load, buckling, seismic load, soil-structure interaction (SSI), sensitivity and thermal effect is considered for design of Moalem Bridge. This paper tries to introduce the design concept and analyses made to check and verify its realization.

Keywords: *Arch bridge, flyover, buckling analysis, soil structure interaction, shear key, internal deck joint.*

1. INTRODUCTION

Arch bridges have long been used for river over passes and viaducts, as a statically efficient, and aesthetically pleasing solutions. The oldest arch bridges date back to 1300 B.C. made by Greeks. Romans developed and spread the technology and art of building masonry arch bridges all over Europe and west Asia for the next millennium. Today concrete and steel arch bridges have replaced the old masonry arches, which have made possible building long span and extra flat arches, due to material's inherent bending capacity and high resistance.

One of the bridge types which arches are rarely utilized for, are urban overpasses. These types of bridges are usually designed to reduce the traffic problems, of urban crossings in growing cities, where existing space for grade solutions are not found.

Flyover's consisting of elevating ramps with several similar spans are typical solutions for such circum-stances. By limiting the slopes to about 5% and free height to about 5m, one riches to an overall 300 m length for a typical flyover.

If the length of bridge is slightly increased an arch bridge in center with sloping tangent girders at sides may be used as an innovative alternative for routine flyovers.

This concept is utilized for an urban development project in center of Semnan city Iran, resulting in an economic and aesthetically prominent flyover which is praised by Iranian Society of Steel Construction (ISSC) as the most valued steel bridge design in 2013. This

paper tries to introduce technical aspects of this bridge and encourage the approach for future urban projects.

2. BRIDGE SPECIFICATIONS

A new flyover bridge is designed to replace the old Moalem Square in central Semnan, a growing city with 200,000 population 216 km east of Tehran the capital of Iran. The steel construction was made on a near by temporarily equipped shop, and erection was performed without diverting or stopping urban traffic at the bridge site. It took 16 months from Jan 2011 to May 2012, with a total expense of 2 million USD to complete the construction. Separate contracts for steel construction and civil works were awarded to local contractors under the supervision of Tazand consulting engineers. The site plan and elevation of the bridge is shown on Fig. 1.



Fig. 1. Moalem Bridge's geometry a) site plan; b) elevation.

The bridge is 19.5 m wide with 4 traffic lanes, in two bands separated by a void median of 0.4 m breadth. It consists of a 5% sloping ramp at west and a 7% sloping one at east, reaching a maximum height of 11 m at center. The total bridge length is 252m with an extension of reinforced soil ramp at each side.

Bridge structure is made of two parts. The central part is made of 3 parallel arches for each band, spanning 66m long and rising 11m high, with rise to span ratio of 1/6,

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continued with similar half arches resting on reinforced concrete piers at 24m each from arch supports.

The side parts consist of, several parallel continuous span girders for each band with 18m and 15m Spans. These girders are tangent to the arch ribs but structurally isolated by internal expansion joints, and resting over reinforced concrete piers, and end abutment blocks. The bridge structural parts are shown on Fig. 1.

The steel arches are tapering I sections with a depth of 1.0m at Crown to 1.5m at supports ending to butterfly shape steel supports with similar flanges and double webs, aiming to hide the irregular support stiffeners. Steel arch supports rest over a pile group of 20 piles, with a rigid pile cap. Arch flanges are 60 cm wide all-over and have varying thickness of 35 mm to15 mm. Arch part details are shown on Fig. 2.

Several transverse diaphragms of wide-flange shape inter-connect the parallel arches, in order to help with transferring of lateral loads to the arch supports.



Fig. 2. Arch part details (in construction time).

The R.C. bridge deck slab consisted of two- way continuous panels dimensioning $3.25m \times 4.5m$ with over hangs. Steel girders and transverse beams supported the deck panels. Shear connectors provided for the composite actions of the R.C deck and steel supports where it is required by design to increase the bending capacity or improve the overall stability.

Using narrow head piers for architectural reasons, steel box transverse diaphragms were used as cantilevers to support the side Girders. These diaphragms rest over two elastomeric bearings on each pier (Fig. 3).

Shear keys are utilized on each pier to prevent the deck from moving transversely over the supporting piers while permitting for the longitudinal thermal and seismic movements.



Fig. 3. Supporting on piers (in construction time).

An innovative internal deck expansion joint utilized for isolating arch part from ramps part. The location of expansion joint is shown in Fig.1 .For free sliding movement under thermal effects, PTFE pad is used in internal deck expansion joint. The details of internal deck expansion joint are shown in Fig. 4.



Fig. 4. Internal deck expansion joint details.

3. STRUCTURAL ANALYSES

Several structural analyses are made on bridge models to check and approve the design concepts. All models are made by SAP2000 software. Preliminary models used for these analyses, were 2D frame element ones, to make parametric studies on bridges overall dimensions and find members sizes. Analyses were made for gravitational dead and moving loads. Transverse distribution of moving loads was made by the distribution factors method of AASHTO 2010 [1].



Final design models used for seismic and Soil-Structure Interaction (SSI) studies where 3D ones considering all transverse members and their connectivities to the main longitudinal elements. Steel structural member were modelled by Frame and the deck R.C. slab by shell elements with reduced stiffness. Micro models made of Shell elements were made to check Von- Mises stresses and fulfil large deformation analyses. Figure 5 shows 3D models of arch and ramp part used for these analyses.



Fig. 5. 3D models. Arch part on the left and ramp part on the right.

3.1. Moving load analyses

Moving loads are defined by Iranian Bridge Code 139 [3] as standard 40 tons truck with distributed 1.5 t/m loads on front and rear for each lane, and one 90 tons bogie and 70 tons military tank all over the bridge. Moving load analyses where made with 2D and 3D models to find design efforts, verify dimensions and sizes, or to make fatigue checks. Results from 3D analyses had a very good conformity with 2D ones with code based lateral distributions. Bending moment for moving loads analyses are shown on Figs 6.



Fig. 6. Bending moment under moving loads (a) Arch part (b) Ramp part.

The fatigue class is C according to AASHTO specifications [1] for carefully detailed welded connections. A typical detail is shown on Fig.7.



Fig. 7. Left: bridge girders connection. Right: bridge girders to diaphragm connection.

3.2. Soil-Structure Interaction (SSI) analyses

Arch supports are expected to resist thrust forces. Pile groups consisting of 20 piles, 1.5 m diameter and 15m long, which rigidly connected to a $23 \times 10 \times 2.5$ m pile caps. Pile groups are designed to resist the thrust force of all arches at each support. Soil is modelled three dimensionally by non-linear springs connected to piles and pile caps. Horizontal displacements are checked that not to exceed pre-assumed ones used for the arch analyses. 3D soil-structure interaction model is shown in Fig. 8.



Fig. 8. 3D model of soil-structure interaction.





3.3. Buckling analyses

Large deformation buckling analyses are made in two levels, first the overall buckling of arches are studied under gravity and thermal loading, and second local buckling in arch supporting steel elements were investigated.

Overall analyses were made on the 3D model with all transverse lateral bracing diaphragms connected to the arches. Analyses gave very conservative safety factors of 12.93, 13.06 for the first 2 modes of buckling respectively, (Fig. 9).



Fig. 9. Two buckling mode shapes (top view) (a) Mode1; (b) Mode2.

To check local buckling of arch supporting elements named butterfly supports which consist of wide stiffened plate's a micro-model is made with steel shell elements, and loaded with arch reaction forces. Local buckling safety factors of 4.15, 4.26 and 4.68 were reached by analyses for the 3 first buckling modes respectively. First buckling modes of arc support are shown in Fig. 10a. Also Von-Mises stress contours are found and investigated for possible local yielding, and their effect on support stability as shown on Fig.10b.



Fig. 10. Arch support analyses: left: local buckling, model SF: 4.15; right: Von-Mises stress contours.

3.4. Seismic analyses

Most of Iranian territory is located on Alpide - Himalayan Belt and thus is prone to high seismic activities. Semnan city is also located on high seismic region (zone 3) according to Iranian seismic code, Standard No 2800 [2], With a Design Base Earthquake (DBE), Peak Ground Acceleration (PGA) of 0.3g.

The longitudinal seismic resistance of the central part depends on behaviour of the arches under horizontal loads acting tangent to the arch's crown by the deck diaphragm. The seismic modification factor is a very low value of 1.5 for arches, due to their non-ductile behaviour. Two central R.C. piers and arch supports framed by transverse rigidly connected diaphragms resist the transverse lateral seismic effects in the central part.

Spectral-modal dynamic analyses are made using Standard No 2800 code [2] specified design spectra. 100 first natural modes of vibration are considered to provide for 95% mass participation. Mode shapes of arch are given for the first 2 modes on figure 11. Orthogonality of earthquakes is simulated by combining 100% each direction seismic action with 30% seismic action in perpendicular direction in 3D models.

Transverse seismic resisting system of the ramps part consists of cantilever piers, and reinforced soil abutment blocks at the two ends. The design assumptions are realized by using transverse shear keys.



Fig. 11. Modes shape of vibrations: left: mode shape 1, T: 0.73 sec; right: mode shape 2, T: 0.39 sec.



Fig. 12. Longitudinal restrainers of ramps part.



Seismic longitudinal forces on the side parts are transferred via deck slab to abutment rigid blocks, made of R.C. walls interlocked with reinforced earth ramps. Longitudinal restrainers of ramps part are shown in Fig. 12.

3.5. Sensitivity analyses

Sensitivity analyses are made to estimate the effect of unpredictable factors which may influence the arch design during its service life. These include excessive horizontal and vertical displacement at supports, unseating of bridge girders at expansion joints, and plastic hinging of shallow arch cross-sections at crown due to excessive bending moments.

Arch support settlement sensitivity analyses are made on a 2D model of one arch. Supports were exposed to alternative horizontal and vertical movements. Analyses show horizontal and vertical displacement in order of 25mm can be tolerated within code specified safety margins, and displacements in order of 50 mm also may be tolerated with 30% reduction in moving loads. One of the several cases of exerted movement to arch support is shown in Fig.13. Geotechnical calculation by the SSI modelling of Section 3.2 estimate the vertical and horizontal support movement under factored loads in order of 5 and 10 mm respectively.



Fig. 13. One of the several cases of exerted movement to arch supports.

The internal expansion joint, which is shown in Fig. 4, used for isolating central arches from side ramps may be the source of unseating of bridge deck girders, under a severe earthquake induced motions. While necessary cautions are made in detail design of the joint (Fig. 4), the effect of possible unseating is considered in sensitivity analyses.

The arch ribs are integrated with the deck girders at crown to form a very shallow aesthetic view. In case of plastic hinging of arch crown stability of the cantilevered triangles are guaranteed by hold down devices used at the central R.C piers.

3.6. Thermal analyses

The 252 m long bridge is equipped with two carefully detailed expansion joints of E100 type, allowing for ± 50 mm movement each, from the as installed position. The expansion joints installation is made at +10 to +20 °c, allowing a ± 40 °c alteration according to design specifications.

For the central arches which are restrained by their fix supports, thermal analyses are made which show the arch vertical movements compensates much of the longitudinal expansion and contraction (Fig .14). Meanwhile thermal thrust in the arch sections and supports have considerable values which govern the arch design in combination with gravitational efforts.



Fig. 14. Thermal deformation of arch: a) expansion deformation, b) contraction deformation.

4. CONCLUSION

Flyovers are increasingly used for newly required over- passes in urban areas. Routine flyovers utilize similar simple span ramping girders, with break points on pier expansion joints. Bridge engineers are familiar with this design concept and its limitations on serviceability and maintenance. Combining side ramps, as a continuous girder with a central arch or several such arches at center may present a different design concept, which has numerous architectural and traffic advantages due to longer central span while structurally and economically reasonable.

Moalem Bridge in Semnan city, central Iran, is introduced as a case study for several detail designs and sensitivity analyses made to realize this design concept.

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