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# Analysis of Dynamic Response of Aqueduct to Seismic Excitations

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***Abstract:*** **-- Aqueduct is a watercourse constructed to convey water over an obstacle, such as natural streams, valley etc. In modern days, the aqueduct is also used for any system of pipe, ditches, canal, tunnels, and bridges which is used as an artificial watercourse. If the structure is constructed in the earthquake-prone area dynamic analysis of structure is necessary. The structure is analyzed by considering pressure effects of fluid, but for special structure simple and yet accurate model for dynamic analysis is needed. To find out fairly accurate results, numerical modeling of water and dynamic analysis is necessary to perform. In this paper, seismic response analysis of a proposed aqueduct in the Pune seismic zone will be performed. Particular effort is devoted to finding a suitable numerical model that can accurately represent the proposed aqueduct design, water-structure interaction, and the effects of bearing properties of the aqueduct on its responses to seismic ground excitation. The result shows that using rigid bearing in the analysis can significantly reduce the aqueduct responses as compared to the bearing pads simulated by elastic link supported aqueduct.**

***Keywords*****: - Aqueduct, Response Spectrum Analysis, Rigid bearing, Elastic bearing, MIDAS Civil.**

## I. INTRODUCTION

Aqueducts are man- made structures that have been crucial part of every civilization in the distribution of the essential but not so ubiquitous element of nature, water. Aqueducts transport water across topographical barriers to their destination, taking various forms and traveling at different levels with respect to the ground such as pipelines and canals. Large navigable aqueducts are used as transportation links for boats or ships. Aqueduct must span a crossing at the same level as the watercourses on each end. It is the structure which is monolithically cast by providing rigidity in the form of rigid links at top of the pier and abutments. But massive load of water in an elevated aqueduct shifts its center of mass further above the ground compared to highway/railway bridges. As a result, the structure becomes more vulnerable to dynamic lateral forces, especially, those due to hydrodynamic effects. During seismic excitation structure gets shaken and crack are form in the superstructure. It is not possible to prevent the damage of structure completely. Therefore to minimize effect of damage, use of different bearing types are necessary.

## II. LITERATURE REVIEW

There are few works carried out by researcher, Wenyi Chen and Hong Hao (2004) worked on dynamic response analysis of large aqueduct to earthquake ground excitations, in which Particular effort is devoted to find a suitable numerical model which accurately represent the proposed aqueduct design, water-structure interaction, and the effects of bearing properties of the aqueduct supports on its responses to seismic ground excitation [1]. Yi Wu, Hai Hong Mo, Chun Yang (2014) worked on the dynamic characteristics of a three-dimensional high frame supported U-shaped aqueduct are studied, in which they used Arbitrary Lagrangian Eulerian (ALE) method and is applied to simulate the interaction effects, the large amplitude sloshing effects of water and effects on the aqueduct structure, coupling effects between the 3D high frame-supported aqueduct and water in it. From results they conclude the Arbitrary Langrangian–Eulerian (ALE) method has great potential in modelling high amplitude standing waves [2]. E. Ercan and A. Nuhoglu worked on Identification of Historical Veziragasi Aqueduct Using the Operational Modal Analysis, in which researcher used destructive and

 

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non-destructive test to find out material as well as chemical properties and by using this properties structure was modelled in finite element software and check for several post-earthquakes and structural health are understood [3]. Bo Wang, Qingbin Li worked on Beam segment element for dynamic analysis of large aqueduct, in which researcher are modelled aqueduct by using beam segment element method and finite element method and dynamic analysis was performed. From result researcher conclude that, in beam segment element method computation time is much smaller than FE model and this method is practical, efficient, and accurate for dynamic response analysis for complex and large span aqueduct [4]. Bhavana Valeti, Samit Raychaudhuri & Prishati Raychaudhury worked on Seismic response of an elevated aqueduct considering hydrodynamic and soil-structure interactions, which gives the effect of hydrodynamic forces and SSI on seismic response of a representative elevated aqueduct model was studied. Frequency domain stochastic response analysis as well as time-history analysis with a series of ground motions of varying hazard levels has been performed. Demand parameters such as base shear and drift ratio are studied for varying heights of water in channels and different parameter site conditions [5]. N. C. Singhal worked on Seismic analysis of an Aqueduct founded on piles, which gives Seismic analysis of an aqueduct has been carried out in longitudinal and transverse directions subjected to postulated earthquake. The flexibility of foundation-soil and sloshing effect of water has been considered and dynamic analysis was performed. The results show that time period and displacement was maximum in transverse direction than that of longitudinal direction [6].

From the literature review it is observed that the researchers worked on the dynamic response of structure by considering effect water pressure, effect of water model, effect of different bearing properties and their location along with soil structure interaction effect. Therefore the present work aims to study the effect of water pressure, water model and different bearings on the structural response of aqueduct.

## III. AIM

To Analyze the Dynamic Response of Aqueduct subjected to Earthquake excitation.

## IV. METHODOLOGY

First, the detail study was done for the existing structure along with design and functioning of rigid bearing and elastic bearing, then study will be carried out on the previous modeling work and new water model were established for the proposed aqueduct structure. By using two type of bearing and different method of water application aqueduct structure was modeled in the finite element software. Then Response Spectrum analyses were performed on structure by considering water application method and different bearing types and comparison was made on the basis of analysis results of proposed aqueduct model. Then on the basis of this results and comparison, conclusion was made.

## V. ANALYTICAL PROGRAM

### A. Aqueduct model

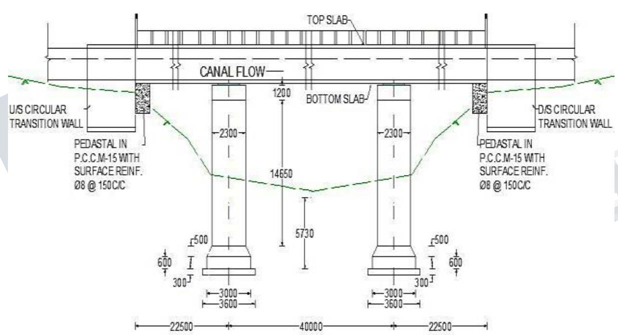


***Fig. 1 Balance Cantilever Aqueduct***

The aqueduct analyzed in this study is Balance Cantilever Aqueduct situated in Pune. The total length of the aqueduct is 85 m, consisting of 3 spans with an end span length of 22.50 m and middle span of length 40 m. The cross section dimension of the aqueduct is 3.6 × 3.0 m along with 300 mm thick reinforced concrete slab and side walls. The reinforced concrete box aqueduct is rest on piers of height 16.0 m and radius 2.10 m as shown in Figure 1.

### B. STRUCTURAL MODEL

The commercial software package Midas Civil, was used for numerical analysis. The structures were modeled by beam and plate elements. Beam elements used to model the side walls of the aqueduct and slabs modeled as plate element and the piers are modeled by beam elements. The material properties and cross-sectional properties of the aqueduct structure were as per the design. In the preliminary design stage, the aqueduct was designed to be rigidly supported resting on piers. In a later stage, elastic bearing was used in order to study the seismic behavior of the structure. In the present study, to verify the accuracy of the numerical model, responses of the aqueduct with rigid support are calculated first. To study the effects of different bearing supports on reducing the seismic responses of the aqueduct, numerical

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analyses for dynamic responses of aqueduct with elastic bearing support of different lateral stiffness were performed. The results were compared with each other and also compared with rigidly supported model.

**C. Link information**

A link object connects two joints, i and j, separated by length L, such that specialized structural behavior may be modeled. Linear, nonlinear and frequency-dependent properties may be assigned to each of the six deformational degrees-of-freedom (DOF) which are internal to a link, including axial, shear, torsion, and pure bending. Rigid link constraints geometric, relative movement of a structure, where degrees of freedom of subordinated nodes called Slave Nodes are constraint by a particular reference node called Master Node were shown in figure 2(a). Elastic links can be defined in a model to simulate elastic bearing pads when analyzing bridge structures were as shown in figure 2(b).

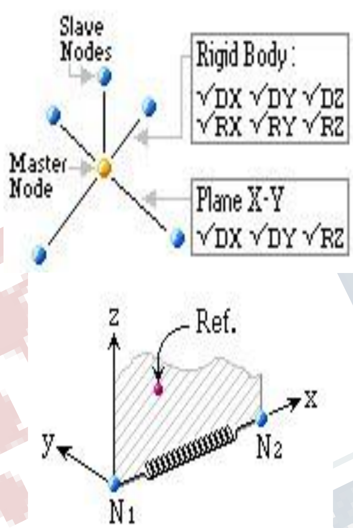


*Fig2. (a) Rigid Link (b) Elastic Links*

**D. Analysis performed**

Dynamic analysis was performing on rigidly supported aqueduct and bearing supported aqueduct. Aqueduct structures were modeled in Midas civil software with rigid link and elastic link support as shown in figure 3 (a) & (b). Response spectrum analysis was carried out for design spectrum (IS 1893:2002) with 5% damping, for seismic zone IV, medium soil type condition. For analysis importance factor was consider as 1.5 and response reduction factor was consider as 5.0. Analysis was carried out by considering two component of earthquake ground motion are considered with scale one for both longitudinal and transverse direction. Analysis results were shown as follows:

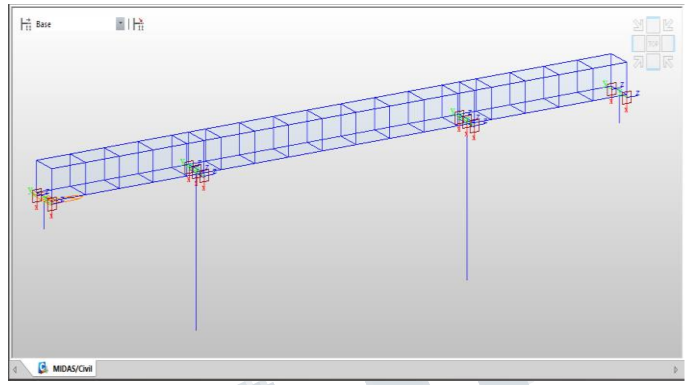

*Fig.3 (a).Schematic diagram of Rigid and Elastic links supported model*

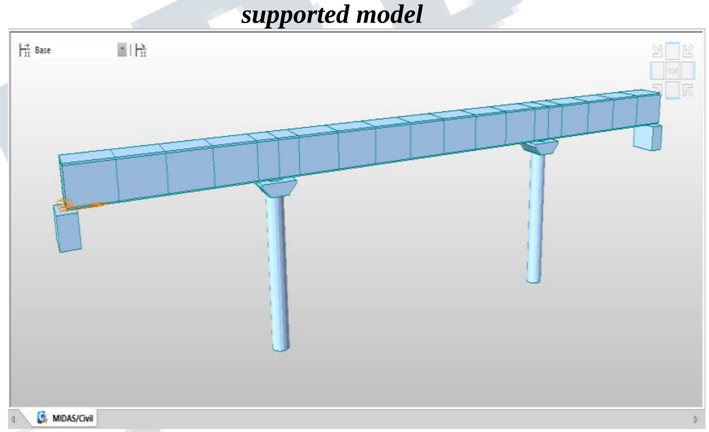

*Fig.3 (b).3-D Rigid and Elastic links supported model*

Following figure 4(a & b) and figure 5(a & b) shows free body diagram of rigidly supported aqueduct and elastically supported aqueduct along with water pressure and water model application method.

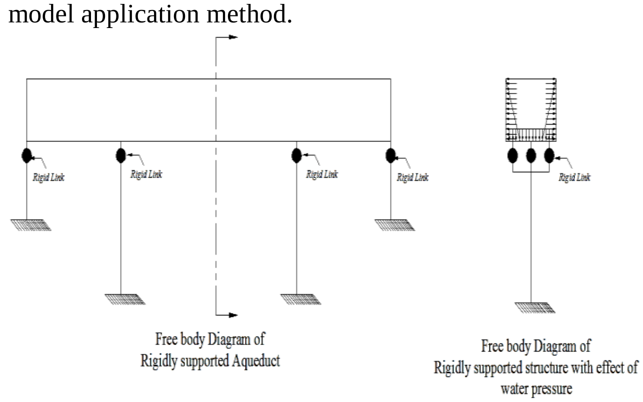


*Fig. 4 (a). Free body diagram of rigidly supported aqueduct considering effect of water pressure*

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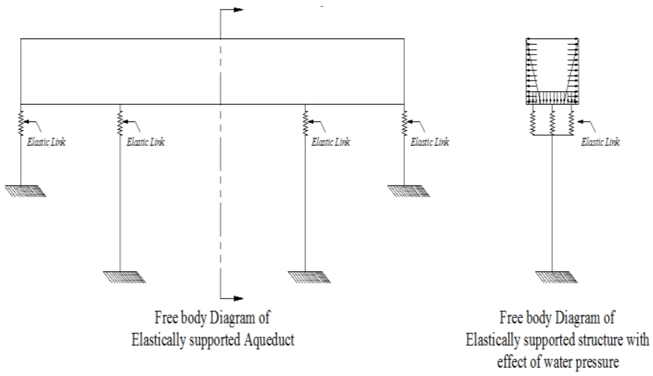


***Fig.4 (b).Free body diagram of elastically supported aqueduct considering effect of water pressure***

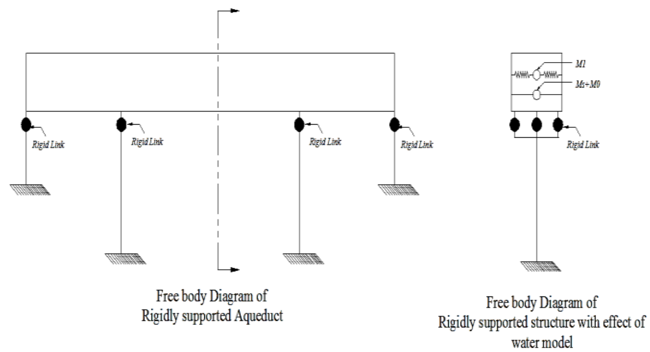


***Fig.5 (a). Free body diagram of rigidly supported aqueduct considering effect of water model***

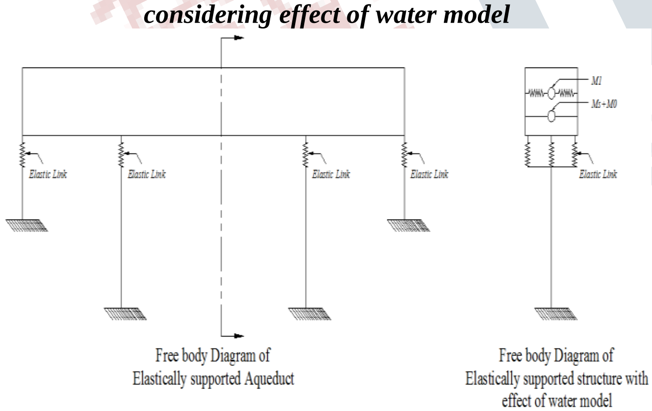


***Fig.5 (b).Free body diagram of elastically supported aqueduct considering effect of water model***

**E. Model information**

During whole analysis study each model is explained by its name is become difficult to understand. Therefore it is necessary to make model nomenclature as simple as possible. Following nomenclature is used for models:

Model 1 = Rigidly supported with water pressure
Model 2 = Elastic Links supported with water pressure
Model 3 = Rigidly supported with water model
Model 4 = Elastic Links supported with water model

## VI. RESULTS AND DISCUSSION

Analysis was done for the four different models i.e. (rigid bearing supported considering effect of water pressure, rigid bearing supported considering effect of water model, elastic bearing supported considering effect of water pressure and elastic bearing supported considering effect of water model) using Midas Civil software. Results were shown in Table 1 for the time period in both directions i.e. longitudinal direction and transverse direction.

***Table 1 Time period***

| TIME PERIOD (sec) | | |
|---|---|---|
| Model | Longitudinal Direction | Transverse Direction |
| Model 1 (Rigid + water pressure) | 0.182 | 0.606 |
| Model 2 (Elastic + water pressure) | 1.313 | 0.889 |
| Model 3 (Rigid + water model) | 0.930 | 1.354 |
| Model 4 (Elastic + water model) | 2.062 | 1.638 |

From the above Table 1, it seen that time period was greater in elastic links supported aqueduct than that of the rigidly supported aqueduct in both with water pressure case and with water model case in both longitudinal and transverse direction.

Displacement results were calculated for both models in longitudinal and transverse direction at three different points. Displacement at pier top i.e. node no. 44 and node no. 80 and center of aqueduct i.e. node no.10394 were calculated which is shown in Table 2.

***Table 2: Displacement Result***

| DISPLACEMENT | | | |
|---|---|---|---|
| Model | Node | Dx (mm) | Dy (mm) |
| Model 1 (Rigid + water pressure) | 44 | 0.713 | 7.070 |
| | 80 | 0.713 | 7.070 |
| | 10394 | 0.819 | 18.540 |
| Model 2 | 44 | 0.00 | 11.420 |

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| | | | |
|---|---|---|---|
| (Elastic + water pressure) | 80 | 0.00 | 11.420 |
| | 10394 | 1.190 | 24.790 |
| Model 3 (Rigid + water model) | 44 | 5.684 | 16.654 |
| | 80 | 5.684 | 16.654 |
| | 10394 | 10.798 | 93.727 |
| Model 4 (Elastic + water model) | 44 | 0.00 | 48.381 |
| | 80 | 0.00 | 48.381 |
| | 10394 | 7.49 | 159.534 |

From the above Table 2, it seen that displacement is maximum in elastic links supported aqueduct model than rigidly supported aqueduct for both cases with water pressure case and with water model case in both longitudinal as well as transverse direction.

## VII. COMPARISION

Dynamic analysis is performed on four different models and displacement results for transverse direction are tabulated. Then displacement in transverse direction calculated theoretically as follows:

i] Rigidly supported with water pressure model [Model 1]

For Node 44 and Node 80

Mass = $M = 88.180\ \text{kN/g}$

Stiffness = $K = \frac{12\ EI}{l^3}$

$$K = \frac{12\ X27386X10^3X0.954}{15^3}$$

$K = 92.850X10^3\ \text{kN/m}$

Frequency = $\omega = \sqrt{\frac{K}{m}}$

$$\omega = \sqrt{\frac{92.850X10^3}{88.180X9.81}}$$

$\omega = 10.36\ \text{rad/sec}$

Time period = $T = \frac{2\pi}{\omega}$

$$T = \frac{2X\pi}{10.36}$$

$T = 0.606\ \text{sec}$

$$\frac{S_a}{g} = \frac{1.36}{0.606}$$

$$\frac{S_a}{g} = 2.244$$

Force acting on node = $F_y = \frac{Z}{2} X \frac{I}{R} X \frac{S_a}{g} XM$

$$F_y = \frac{0.24}{2} X \frac{1.5}{5.0} X2.244X88.180X9.81$$

$F_y = 69.880\ \text{kN}$

Displacement in transverse direction = $D_y = \frac{F_y}{K}$

$$D_y = \frac{69.88}{92.85X10^3} \qquad D_y = 7.520\ \text{mm}$$

By analytically displacement in transverse direction is 7.02 mm.

**2. For Node 10394**

Force acting on structure =

$$F_y = \text{wt. of slab} + \text{wt. of wall} + \text{wt. of water}$$

$F_y = 119.23 + 33.84 \qquad F_y = 153.07\ \text{kN}$

Displacement in transverse direction =

$$D_y = \frac{F_x}{K}$$

$$D_y = \frac{153.07}{92.85X10^3}$$

$D_y = 18.54\ \text{mm}$

By analytically displacement in transverse direction is 18.08 mm.

Displacement results for further models are calculated in same manner as above which is shown in table 3.

***Table 3: Displacement result***

| DISPLACEMENT (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Node | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
| | Analytical | Numerical | Analytical | Numerical | Analytical | Numerical | Analytical | Numerical |
| 44 | 7.07 | 7.52 | 11.42 | 11.03 | 16.65 | 16.76 | 48.38 | 20.31 |
| 80 | 7.07 | 7.52 | 11.42 | 11.03 | 16.65 | 16.76 | 48.38 | 20.31 |
| 10394 | 18.54 | 18.54 | 24.79 | 27.63 | 93.72 | 53.92 | 159.53 | 79.05 |

## VIII. CONCLUSION

Response spectrum analyses were done for all four models. In earthquake analysis mainly we compare the result for time period and displacement of the structure. So following conclusion was made from due above analysis results. Base on the studies carried out, following are the conclusion drawn:

1. In response spectrum analysis, it is seen that displacement is maximum in elastically supported structure than rigidly supported structure.
2. It is also seen that, the displacement value is decreased when water pressure is considered rather than water model.
3. The effect on time period is found out to be maximum in elastically supported structure than rigidly supported structure.

4. Also, the time period decreases when water pressure is considered rather than water model
5. The deliberating parameters of aqueduct analysis are projected as rigid supported structure with water model effect.

From above discussion it is clearly seen that use of water model give more realistic results than water pressure. Also the use of elastic bearing vibrates structure more than rigid bearing. Therefor use of water model and use of rigidly supported structure would greatly reduce aqueduct responses to seismic ground motion as compared to using water pressure elastic links supported aqueduct. The study also found that if the aqueduct is relatively stiff, the effect of convective mode of water vibration on aqueduct is insignificant and water inside the aqueduct structure can be considered as static mass in the analysis.

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