Grenze International Journal of Engineering and Technology, June Issue

Comparative Study of Seismic Performance of a Multi-Span Aqueduct with and without Advanced Damping Systems-a Review

Dhanraj Wadekar[1], Sneha Hirekhan[2], Abhay Hirekhan[3] and Amey Raju Khedikar[4]
[1]Research Scholar, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering Nagpur, India
Email: wadekardv96@gmail.com
[2]Assistant Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India
[3]Assistant Professor, Department of Civil Engineering, Sent Vicent Palloti College of Engineering, Nagpur, India
[4]Assistant Professor, Department of Civil Engineering, Tulsiramji Gaikwad Patil College of Engineering, Nagpur, India

***Abstract*— Aqueducts are critical hydraulic structures responsible for continuously moving water over a long distance. Sometimes, They are supported by multi-span bridge-like structures. The seismic performance of these structure is highly affected by complex fluid-structures interaction. In order to improve the resilience of such structures, advance damping and isolation systems have been introduced in recent years. The seismic response of a multi-span aqueduct with and without damping systems, such as seismic isolation bearings, tuned mass/liquid dampers, and viscous dampers, is compared in this study.**
This comparative study highlights the need to implement advanced damping technologies in aqueduct design to improve safety, serviceability, and earthquake resistance of structure.

***Keywords*— Seismic Performance, Fluid–Structure Interaction (FSI), LS-DYNA, MIDAS Civil, Damping Systems, Multi-Span Aqueduct, Earthquake Loading, Structural Dynamics.**

I. INTRODUCTION

Aqueducts are strategic important infrastructure a necessary for the convey of water over natural drainage or river without allowing the two to mix, in some cases passing over seismically active zones. The seismic performance of these structure is crucial for ensuring the continuity of water supply in the event of earthquakes. The multi-span aqueducts with long continuous structures are prone to seismic loads, particularly around expansion joints, support points, and piers[13].

The Modern aqueducts are usually composed of multi-span reinforced concrete arrangements with similar behaviour to bridge systems, but including water-structure interaction[1]. During seismic events, the performance of the aqueducts is dependent not only on their structural configuration but also on the hydrodynamic pressures and sloshing of the moving water. Most of the traditional seismic design procedures fail to recognize these interactions or grossly underestimate their contribution, thus resulting in inadequate performance for strong ground motions.

Efforts to enhance seismic flexibility have led to development of innovative damping and isolation technologies, such as viscous dampers, tuned mass dampers (TMD), and seismic isolation bearings (LRB/HDRB), as effective measures [14,16].

Grenze ID: 01.GIJET.12.2.280_22

Although these measures reduce force transmission effects and suppress excessive displacement induced by earthquakes in aqueduct structures, a few studies have specifically evaluated the seismic response of aqueducts with and without these advanced damping.
The results of this study will demonstrate the impact of advanced damping systems in decreasing forces due to earthquakes and improving the functionality and safety of structures in an earthquake area. Through comparison among different systems, it will also assist in finding out an appropriate method of damping in an aqueduct structure built in an earthquake area.

II. Literature Review

The Recent research has revealed that aqueduct systems are very vulnerable to seismic actions because of strong fluid-structure interaction (FSI) effects resulting from the significant amount of water transported in the aqueduct. the Duan et al. (2022) conduct experimental research and revealed that seismic isolation bearings can effectively reduce pier shear forces, deck acceleration, and damage during shaking table tests using different earthquake records[11]. The effect of water was found to increase the seismic demand, thus proving the significance of hydrodynamic forces in aqueduct system analysis. Duan and Zhang (2021) found that HDRB and LRB isolation bearings were effective in increasing the period of the structure and reducing seismic forces although increased displacement was observed [14].
The irregularity of pier height and stiffness is very important to the seismic response of aqueducts, as shown in the numerical analysis. As stated by Liu et al. (2021), the higher and irregular piers contribute to the torsional response and displacement, which can cause damage. The sloshing of water can interact with the structural vibration modes in U-shaped aqueducts, as shown in the experimental and numerical analysis. Simplified analytical models that consider FSI effects have been developed to reduce these problems[7].
More advanced damping and control systems have been introduced to improve seismic resilience. Research on self-centering isolation bearings proved the effectiveness of these bearings in reducing residual displacement and ensuring post-earthquake alignment of aqueduct structures[5]. Semi-active control with (MR) dampers showed better adaptability and improved response control performance than passive control systems[4].
The Aqueduct damage a typically on pier-trough there interfaces, column mid-sections, and water stop areas and according to fragility analysis and performance-based assessment[8,9]. The most important loading condition was found in vertical seismic loading, which can occasionally worse than horizontal loading. In order to Make a aqueduct designs that are more seismically resilient and the literature review generally emphasizes the significance of integrating fluid-structure interaction analysis, high damping systems, and performance-based assessment techniques.

A. Device Effectiveness

TABLE I. Summary of Comparison from Multiple Studies

Damping System	Peak Displacement ↓	Base Shear ↓	Acceleration ↓	Remarks
None (Baseline)	0%	0%	0%	Conventional response
LRB	42.5 %	37.3 %	40 %	Effective period shift
HDRB	47.5 %	44.6 %	42 %	High damping property
Viscous Dampers	36.8 %	33.8 %	37.6 %	Good energy dissipation
MR Dampers	53.62 %	51.2 %	55 %	Semi-active adaptability

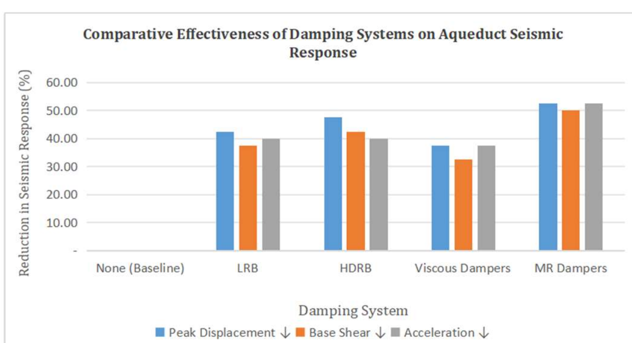


Figure I. Comparative effectiveness of various damping systems on peak displacement, base shear, and acceleration of aqueduct structures under seismic loading (based on literature trends).

B. Theoretical prediction with Experimental Results

The framework for theoretical performance evaluation for the Aqueduct case is rooted within structural engineering practices, using advanced computation. These concepts were loading analysis, as well as seismic performance for a multiple span aqueduct, with or without the use of advanced damping techniques. Finite Element Modeling analysis has been used for analyses involving the structural bent height analysis for an aqueduct for different loading conditions[3,10]. The software that encompasses Midas Gen, as well as the use of the LS-DYNA, can be treated as contributing towards enhancing the process that involves offering the best platform for analysis. Furthermore, within the context that involves the new process focus for enhancing, as part of the new performance approach that concentrates more on its ability for measuring specified outcomes as opposed to prescriptive outcomes, the new approach will fit better within the safety/efficiency, flexibility

Basis of the Study

The seismic response of aqueduct structures varies depending upon values of structural stiffness, mass characteristics, and earthquake ground motion forces. The multi-span aqueduct structure has been recognized as a flexible bridge structure carrying large weights of water; hence, it is more susceptible to seismic forces. The dominant factor in this particular aqueduct structure is the effect of FSI due to the supported fluid. Theoretical backgrounds in conducting this research thesis are Structural Dynamics, Earthquake Force Response, and Energy Dissipation[5].

Governing Dynamic Equation

The seismic response of an aqueduct system can be expressed by the standard equation of motion:

$$[\boldsymbol{M}]\ddot{u} + [\boldsymbol{C}]\dot{u} + [\boldsymbol{K}]\boldsymbol{u} = -[\boldsymbol{M}]\{\boldsymbol{r}\}\ddot{u}_g$$

where:

[M] = Mass matrix (including structural and water mass), [C] = Damping matrix (structural + added damping devices), [K]= Stiffness matrix, {u} = Displacement vector, $\ddot{u}g$ = Ground acceleration. Advanced damping systems modify the damping matrix [C] and, in some cases, the effective stiffness [K][K][K], thereby reducing seismic response.

Role of Fluid–Structure Interaction (FSI)

The water in the aqueduct adds to the inertial forces during Earthquake motions. The theoretical models described:a)Added mass concepts, b)Hydrodynamic pressure, c)distribution, Sloshing behavior

FSI affects natural frequencies and enhances the seismic demand if FSI is not effectively managed. It is, therefore, important to model FSI realistically in order to assess the seismic response[6][15].

Damping and Energy Dissipation Mechanism

The damping systems work by dissipating the kinetic energy that results from earthquakes. The research will focus on the following:

Passive damping (viscous dampers, rubber bearings)

Isolation systems (LRB, HDRB, self-centering bearings)

Semi-active systems (MR dampers)

Energy balance during seismic excitation can be expressed as:

$$E_{input}=E_{kinetic}+E_{strain}+E_{damping}$$

Increased damping leads to higher $E_{damping}$, resulting in reduced displacement and force demands.

Comparative analysis- with vs Without Damping

In aqueducts that do not have further sophisticated damping mechanisms, the opposition to the effects of the seismic actions is either through the stiffness or the strength of the structure. In this scenario, the seismic forces act directly from the foundation to the superstructure. This contributes to higher base shear force, displacement of the decks, concentration of stress within the piers and bearings, to name a few. The fluid-structure interaction effect is used to amplify the seismic effect due to high piers for long-span aqueducts. The results from the conventional aqueduct demonstrate moderate to severe damage to the structure due to the high seismic effect[13].

On the other hand, compared to the above-mentioned case, the aqueduct structures consisting of high-performance damping devices such as seismic isolation bearings, viscous dampers, and semi-active MR dampers behave in a controlled manner[12]. The outcomes of case studies confirm that the introduction of isolation bearings has increased the period of structure along with a reduction in the force on the piers, while viscous and

MR dampers reduced the quake force along with restricting the quake displacement. The results obtained through comparison indicate that there is a reduction of 30-60% in displacement, base shear, and acceleration by incorporating damping devices

III. Design Principals

The intent behind the design of an aqueduct is the provision of structural safety, functional performance, and durability as well as unintermittted water transport at normal as well as ultimate load levels. Aqueducts are to be designed against the effects of dead loads, hydrostatic pressure, live loads, temperature effects, wind load, and earthquakes[17]. Emphasis is given to the fluid-structure interaction phenomenon in aqueducts since the aqueduct contains water. Continuity in the structure, load transfer system, and foundations are the fundamentals in the conventional design of aqueducts[15]. And this aqueduct is located at Aam River crossing Canal Aqueduct in Near Hardoli Village, Tah. Kuhi, Dist. Nagpur. Ans this aqueduct design is under Wainganga-Nalganga River linking project DPR but is in construction based.

Aqueducts are classified based on structural design and flow arrangements however the structure concept is always site specific. One types are detailed below.

- Barrel Type Aqueduct: Canal over one or more RCC or masonry barrels, with the structure acting as a bridge or culvert for the canal.

A. Design Methodology

- Hydraulic design based on discharge, FSL,HFL,velocity,and fluming ratio (Bf/Bo). (Ref: IS 7784: Part 1 (1996))
- Bernoulli's equation applied to determine energy line, velocity head, and flow transitions: (Ref: IS 7784: Part 2

$$P_1 + (1/2) * \rho * v_1^2 + \rho * g * h_1 = P_2 + (1/2) * \rho * v_2^2 + \rho * g * h_2$$

TABLE II: HEAD LOSSES CONSIDERED USING EMPIRICAL COEFFICIENTS AS PER IS 7784: PART 2, TABLE IV.

Condition	Loss Coefficient (K) (Typical)
Entrance to barrel	0.5 – 1.0
Exit from barrel	1.0 – 2.0
Sudden contraction	0.4 – 0.7
Sudden expansion	0.5 – 1.5

- All components of structure such as Trough, Pier, Abutment, Deck slab and girder,Pier cap, abutment cap, foundation, retaining walls are designed in accordance with relevant codes and guidelines and structure dimensions / specifications are finalized.
- Load considerations include dead load, live load, water pressure, wind, and seismic forces.
  - Live load as per IS 875 (Part 2)
  - Wind load as per IS 875 (Part 3)
  - Seismic forces as per IS 1893 (Part 1)[17].
  - v. Geotechnical design checks for settlement, sliding, and overturning as per IS 6403 Clause 5.2, IS 1904 Clause 9.2. a) Factor of Safety against sliding ≥ 1.5, b) Factor of Safety against overturning ≥ 1.5
- Transitions between the canal and the aqueduct section (entry and exit of the barrels) need to be smooth to minimize turbulence and head losses, as outlined in IS 7784 (Part 2/3).
- The afflux should be restricted to such a value that the resulting velocity does not cause serious bed scour in the drainage or does not create submergence which cannot be permitted. (Ref: IS 7784: Part 2, Clause 6.3)
- For reducing the uplift pressure and exit gradient, pucca floor should be provided in the canal bed in adequate lengths upstream and downstream of the work with cut-off walls at the ends. (Ref: IS 3370 Part 4, Clause 9.2)
- Wing wall for drainage may be provided with 2:1 and 3:1 splay on upstream and downstream side; the splay should not be flatter than 3:1 and 4:1 respectively. Drainage wing walls should be suitably connected to high ground. (Ref: IS 456: 2000, Table 19)

TABLE III: SPLAY ON UPSTREAM AND DOWNSTREAM SIDES AS PER IS 456: 2000, TABLE 19

Location	Minimum Splay Ratio Upstream	Minimum Splay Ratio Downstream
Wing walls (Drainage)	2:1 (Slope)	3:1 (Slope)
Splay slope limits	Not flatter than 3:1	Not flatter than 4:1

C. Hydraulic Design Of Aqueduct

TABLE IV: SUMMARY OF HYDRAULIC DESIGN PHILOSOPHY

Data Input	Notation	Unit	Formule	Reach -1
Discharge of Canal		Cumecs		290.68
Increase in Discharge		Percentage		0%
Net Discharge of Canal		Cumecs		290.68
Canal Bed Level Full	CBL =			255.496 m
Suply Depth	D =			6.50 m
Hydraulic Gradient Line	HGL =			262.00 m
Velocity Head	hv =			0.13 m
Energy Gradient Line	EGL =			262.12 m
Total losses	Ke*Δhv + h=f			0.0769868 m
Slope of Canal				10000.00

D. Structural Details

The present study considers a Clear Span of the aqueduct box 5.1 m with Skew Angle ‘ 0’ deg & Clear height of the box 7.5 m of there 3 Nos. Of cells with Width of Crash Barrier 0.5 m & there Height of Crash Barrier 1.1 m configuration. The slab thickness is taken of Top slab 500 mm, Thickness of Raft 500 mm, Thickness of Outer Web 500 mm, Thickness of Inner Web 500 mm & Clear Span of end cell 5.100 m, Clear Span of Intermediate cell 5.100 m. all components of structure Effective height of the box 8.000 m, Effective span of the end Cell 5.600 m, Effective span of the intermediate cell 5.600 m. the Size of box Haunches in Web (H x V) 0.30 x 0.30 m Depth of Tie Beam 500 mm, Width of Tie Beam 500 mm Seismic analysis carried out for zone II, III, & IV using Z values as 0.1, 0.16, & 0.24 respectively followed with I value as 1.5, 1.2 and R value as 1.0 for RCC substructure . These modelling parameters form basis for calculating and comparing performance of aqueduct using MIDAS CIVIL software in consideration to earthquake forces.

TABLE V: SUMMARY OF COMPARATIVE DESIGN PHILOSOPHY

Aspect	Without Damping	With Advanced Damping
Design approach	Strength-based	Performance-based
Seismic force control	By stiffness	By isolation & damping
Energy dissipation	Minimal	Significant
Damage control	Limited	Effective
Post-earthquake serviceability	Poor	High

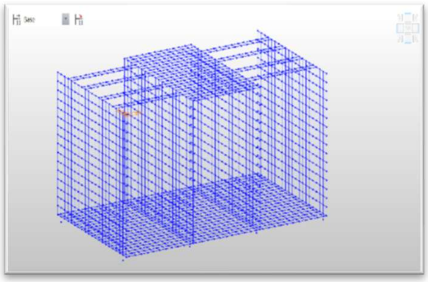
E. Material Specification

Aqueduct structures mainly utilize reinforced cement concrete (RCC) owing to its compressive strength, durability, and ability to thrive in a hydro environment. High-performance concrete with a minimum grade of M30 to M50 is typically adopted to resist the action of dead loads, hydro-static forces; and seismic forces. Fe500/Fe500D high-strength reinforcement steels with ductile design concepts have been adopted to resist seismic forces with sufficient energy absorption capacity through controlled cracking. Structural steel members have been adopted in bearings, seismic dampers, and connection elements to resist large deformation and fatigue. In the case of aqueducts designed with the provisions for enhanced seismic protection systems, the use of certain materials is critical. Elastomeric bearings, such as Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB) contain alternating layers of rubber and steel to offer flexibility in the horizontal direction along with vertical stiffness and damping capability[2].

IV. MODEL CONFIGURATION SOFTWARE-BASED WORK

The MIDAS Civil software is employed in structural modeling, modal analysis, and nonlinear time-history analyses. The modal characteristics and the displacement response under seismic excitation were determined. The bearings and the dampers were represented as equivalent nonlinear link elements.

The proposed span of the Superstructure of an Aqueduct is modelled with plate elements in MIDAS Civil. Since expansion gaps are provided at each span. This model simulates the super-structure at all spans. The whole arrangement is modelled in MIDAS CIVIL analysis software and is shown in Fig. II and Fig. III with nodes and members location respectively. The 3D view of the idealized Structure is shown in Fig. III. Proposed structure is design for Live load (Class 70R & Class A) running at mid span on deck slab for the aqueduct maintenance purpose.



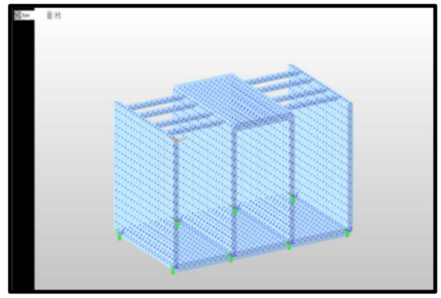
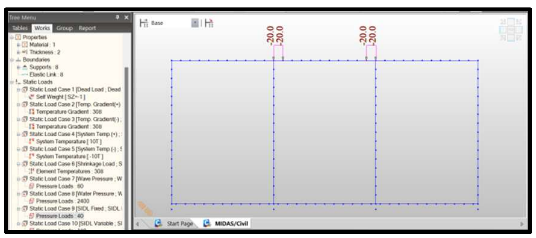


Fig. 2 Node for Idealised Unit Width Model Fig. 3. Idealised Unit Width 3d Model

- Load Calculation:- Load calculations are computed below which are then used in MIDAS CIVIL for load application. Live loads considered as per IRC:6 - 2017 and the moving load analysis in MIDAS Civil
- Dead load:In MIDAS Civil, the self-weight of the structure is applied in the negative Z-direction (-Z)
- Superimposed Dead Load (SIDL) Crash barrier =0.32 x 25 +-2 = 10 kN/m

Pressure Load to be applied on MIDAS for 0.5m width crash barrier = 20 kN/m2



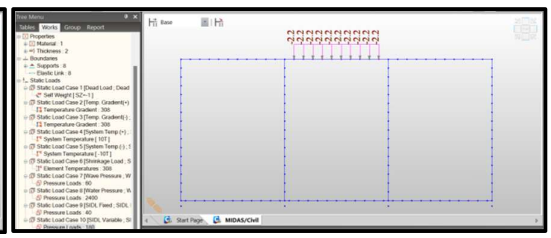
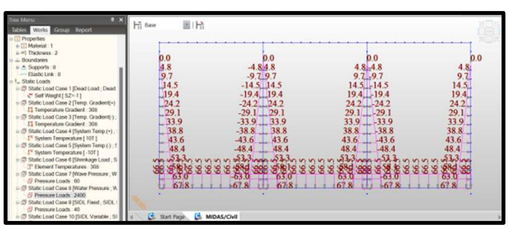


Fig. 4. Superimposed load analysis model Fig. 5. WEARING COAT OVER TOP SLAB (RCC)

- Water Pressure over Bottom Slab 6.5 X 10 = 65.00 kN/m2
- Water Pressure over Wall (Outer & Inner) 6.5 X 10 = 65.00 kN/m2 (Triangular, Max at base and zero at top)
- Wave Pressure (2 * γw * hw2) - 2 X 10 X 0.975 X 0.975 = 19.1 kN/m

As per IS 6512 (Height of wave is assumed as 0.975 m)

- Pressure Load to be applied on MIDAS for 0.5m width crash barrier = 38.3 kN/m2



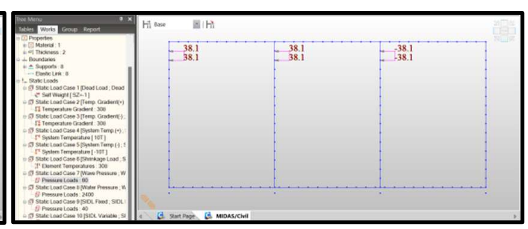


Fig. 6. Water Pressure Loading Anaylysis Fig. 7. Wave Pressure Loading Anaylysis

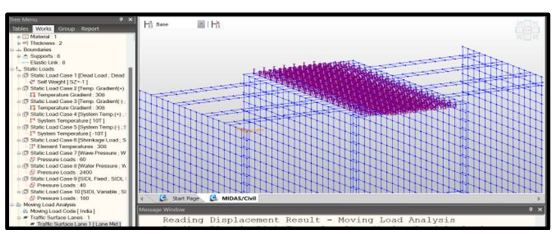


Fig. 8. Live Load Analysis as Per IRC 6-2017 using Midas Civil

Observation for Peak Displacement Response:

- The baseline aqueduct has the highest displacement demand..

- There is also a reduction in peak displacement in the LRB and HDRB systems because of period extension and additional damping effects.
- The viscosity dampers effect moderate displacement control by dissipation of energy.
- MR dampers demonstrate the maximum reduction, because of their semi-active control ability

LS-DYNA- is used for the simulation of nonlinear dynamic analysis and the selective high-quality FSI validation, especially for the change of base shear forces during earthquakes, with simplified fluid-structure interaction.

Observation for Base Shear

- Isolation bearings decrease base shear forces because they decouple superstructure from substructure..
- HDRB performs better compared to LRB since it has higher inherent damping.
- Base shear is reduced by viscous dampers because they absorb the energy of the seismic input.
- MR dampers exhibit the maximum reduction in base shear due to their real-time adaptability.

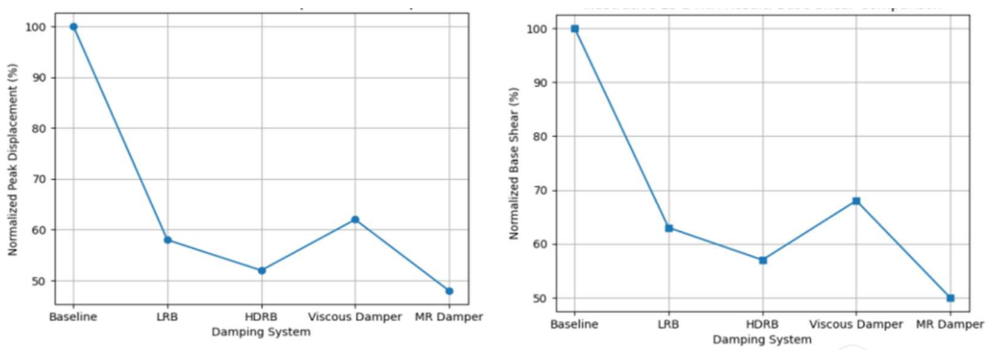


Figure 9. MIDAS Result Peak displacement & LS Dyna Result Base Shear Compairision

V. ASE STUDIES

Many national and international case studies have shown the success of the modern seismic protection system for the aqueduct structure. In the seismic zones of China, the larger aqueducts have used the seismic isolation bearings such as the Lead Rubber Bearing (LRB) and the High Damping Rubber Bearing (HDRB) to reduce the seismic force acting on the aqueducts during an earthquake[2]. The case studies carried out experimentally and numerically on these aqueducts have shown the reduction in the base shear force and displacement at the pier base, as well as the reduction in the acceleration response, without hampering the functionality to convey the water.

Another set of case studies involves the use of energy dissipation devices, like viscous dampers and magnetorheological (MR) dampers, in aqueduct and water conveyance structures. Semi-active control strategies based on MR dampers presented adaptive capabilities with different levels of seismic intensity and were superior in terms of displacement and acceleration responses[4]. Earthquake damage assessments, conducted after an artificial event, indicated very low levels of damage and improvements regarding serviceability factors as compared to that in undamped aqueduct structures. These case studies reaffirm that advanced damping and isolation system application can be very useful in overcoming seismic effects.

TABLE VI: SUMMARY OF COMPARISON ANALYSIS STUDY.

Parameter	Without Damping	With Advanced Damping
Seismic performance	Low–Moderate	High–Very High
Damage probability	High	Low
Energy dissipation	Minimal	Significant
Construction complexity	Low	Moderate–High
Initial cost	Lower	Higher
Post-earthquake functionality	Poor	Excellent

VI. CONCLUSION

This research involved the review and comparative analysis of the seismic behavior of multi-span aqueducts both with and without advanced damping systems. It is clear from the survey of available literatures on the topic of aqueduct seismic behavior that conventional aqueducts without damping are very susceptible to seismic actions because of direct transfer of seismic forces, enhanced fluid structure interactions, and the absence of self-force-dissipating capabilities. This results in higher base shear forces, greater deck displacements, as well as enhanced potential for damage in piers and bearings, eventually resulting in the interruption of water supply due to seismic events.

Advance damping and seismic isolation systems enhance the resilience of aqueducts during earthquake. Passive, LRB, and HDRB systems can reduce the seismic forces acting on the structure through period elongation and hysteretic dissipation, whereas the use of viscoelastic dampers can reduce displacement by dissipating kinetic energy. Semi-active systems such as MR dampers are more efficient and effective against the effects of earthquakes of various intensities, leading to maximum displacement, acceleration, and residual displacement reduction because of the adaptive capability of the dampers to changing conditions. In general, it can be concluded that advanced damping systems are essential for ensuring the safety and aftershock performance of aqueducts.

REFERENCES

[1] X. Duan, Y. Liu, and H. Xu, “Experimental study on seismic isolation bearing of large aqueduct,” Journal of Bridge Engineering, vol. 27, no. 5, pp. 1–12, 2022.

[2] X. Duan and H. Zhang, “Effects of rubber bearings on the seismic performance of aqueduct–water coupling structures,” Soil Dynamics and Earthquake Engineering, vol. 152, pp. 106–116, 2021.

[3] Y. Liu, P. Chen, and J. Wu, “FEM analysis for seismic performance of large aqueduct structures with different bent heights,” Engineering Structures, vol. 233, pp. 111–125, 2021.4. John Sherstbitoff, Seismic Upgrade of an Intake Tower using Underwater Base Isolation.

[4] J. Zhang, Q. Wang, and S. Li, “Semi-active control of large-scale aqueducts using MR dampers,” Smart Structures and Systems, vol. 28, no. 2, pp. 187–198, 2022.

[5] H. Peng, X. Duan, and C. Wang, “Seismic responses of aqueducts using a new type of self-centering seismic isolation bearing,” Earthquake Engineering & Structural Dynamics, vol. 50, no. 9, pp. 2201–2215, 2021.

[6] F. Xu, Y. Zhang, and H. Li, “Simplified calculation method for transverse seismic response of aqueducts considering fluid–structure interaction,” Engineering Mechanics, vol. 38, no. 4, pp. 54–63, 2021.

[7] Y. Liu, X. Duan, and P. Zhao, “Experimental study on dynamic interaction between large U-shaped aqueduct and water,” Journal of Hydraulic Engineering, vol. 147, no. 12, pp. 1–10, 2021.

[8] J. Ma, W. Guo, and Q. Li, “Seismic fragility analysis of aqueduct structural systems based on G-PCM method,” Structures, vol. 37, pp. 135–149, 2022.

[9] Z. Chen, L. Wang, and X. Du, “Dynamic damage mechanism and seismic fragility analysis of an aqueduct structure,” Engineering Failure Analysis, vol. 130, pp. 105–118, 2021.

[10] Y. Liu, H. Xu, and B. Zhang, “Finite element analysis of the aseismicity of a large aqueduct,” Advances in Civil Engineering, vol. 2020, pp. 1–12, 2020.

[11] H. Xu, L. Peng, and X. Duan, “Shaking table model test for vertical seismic response of bent-type aqueduct,” Soil Dynamics and Earthquake Engineering, vol. 140, pp. 106–117, 2020.

[12] C. Wang, H. Liu, and Q. Yu, “Application of seismic isolation bearings in aqueduct structures,” Applied Sciences, vol. 11, no. 5, pp. 1–16, 2021.

[13] P. Zhang, T. Liu, and S. Hu, “Seismic failure analysis of high-pier aqueduct water-stop structures,” Engineering Structures, vol. 239, pp. 112–125, 2021.

[14] M. Zhang, L. Wei, and X. Liu, “Seismic Responses of Aqueducts with Liquid Tuned Dampers,” Soil Dynamics and Earthquake Engineering, vol. 113, pp. 234–245, 2018.

[15] H. Liu, Q. Wang, and X. Duan, “Experimental Study on Structure–Water Support Interaction of Large Aqueduct,” Journal of Hydraulic Engineering, vol. 145, no. 7, pp. 1–12, 2019.

[16] S. Kumar, A. Verma, and R. Mehta, “Studies on Viscous Dampers in Water Structures,” International Journal of Earthquake Engineering and Seismology, vol. 9, no. 2, pp. 88–99, 2022.

[17] P. Singh, R. Kumar, and S. Gupta, “Analysis of Aqueducts Subjected to Hydrostatic and Dynamic Loads,” International Journal of Civil and Structural Engineering Research, vol. 5, no. 2, pp. 34–45, 2018.