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Research Article

Investigation of the seismic response of irrigation channel using Coupled Eularian-Lagrangian approach

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ABSTRACT

While devastating earthquakes affect cities, they can also cause serious damage to irrigation structures in agricultural areas. Cracks and structural deteriorations may occur in water structures using concrete such as dams, aqueducts and open channels. This study investigates the earthquake response of irrigation canals through fluid-structure interaction analysis. The earthquake response of an irrigation canal was examined by establishing fluid-structure interaction. Finite element models, with material properties and dimensions determined, were created and analysed with destructive earthquake records. In the finite element model, the behaviour of water inside the channel is simulated using the Coupled Eulerian-Lagrangian (CEL) approach. In the analyses, displacement and stress values were examined in the model without water, and in addition to these, fluctuations on the water surface were examined in the model with water. The observed changes are shown with graphs and contour diagrams. As a result, it was shown that hydrodynamic effects reduced horizontal displacements by 42% but increased the maximum principal tensile stresses by 49% and the maximum principal compressive stresses by 75%, compared to the non-water model. In addition, it was observed that in both models, the dynamic analysis values at the time of the earthquake increased by approximately 7–13 times the static values before the earthquake. These findings underscore the importance of dynamic analysis using fluid-structure interactive models for safeguarding irrigation structures against seismic hazards, thereby ensuring food security in vulnerable agricultural regions. Therefore, it is important to perform dynamic analysis with fluid-structure interactive models for irrigation structures exposed to destructive earthquake forces.

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1. Introduction

Today, the world's population is rapidly increasing, and this situation is exerting significant pressure on the management of water resources. While the growing population increases the demand for water, the fact that water resources are limited makes water management more critical. In this context, the sustainable use and distribution of water is becoming increasingly important (Cosgrove and Loucks 2015; Sophocleous 2004). Water management involves the effective use, distribution and conservation of water. With the increasing population, there are increases in water consumption areas such as agricultural irrigation, industrial use and urbanization. The growing population and urbanization have driven a rapid expansion in the construction sector (Canbaz et al. 2021). While this situation requires more efficient use of water resources, it also requires the development of sustainable water resources management strategies. Management of water resources includes distributing water equitably, reducing the risks of water scarcity, and protecting water resources (Jury and Vaux 2007; Pedro-Monzonís et al. 2015). With the increasing population, using water resources more efficiently and protecting them for future generations becomes even more important. As a result, while the increasing population

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makes water management more important, strategic planning and implementation is required to effectively use and protect water resources. In this context, sustainable water management policies and projects are vital to meet the water demand of the increasing population and to transfer water resources to future generations. Channels constitute an important part of irrigation systems and are structural elements that enable the distribution of water to irrigate agricultural lands (Angelakıs et al. 2020; Ertsen 2010). These canals are usually placed on prefabricated legs and are generally built-in rows with 5-to-7-meter intervals. The observation and laboratory tests conducted to examine the current condition of the ducts made between 1960–1966 were crucial. In these tests, carried out in laboratories, important characteristics such as weld strength, tensile strength, yield point, and elongation at break were examined. As a result of these tests, it was determined that the ducts produced were suitable for prefabricated structures (Uluöz and Tayakısı 2003). Such tests are essential for determining the quality and performance of building materials and are widely used in the construction industry to ensure reliability. The outcome of these tests indicates how reliable a particular material is under certain conditions, thereby helping to determine its suitability. Channels are the basic building blocks of the flume and allow water to flow in a certain direction. Flumes are generally arranged prefabricated and designed as small water channels. Generally, their cross-section can be elliptical or circular (Fig. 1). An important feature of these flumes is that the water level can be kept at the desired level by changing the foot heights. In this way, the slope of the channel is adjusted to ensure that the water remains at the desired level. This adjustment is made depending on irrigation requirements and the topography of the land. These channels are used to provide water to farmers according to the water demand system or unit field unit water system to meet irrigation needs. These systems ensure the effective distribution of water and regular irrigation of agricultural lands. In addition, balanced distribution of water increases agricultural productivity by meeting the water needs of plants (Özbek 1987). They are used for various purposes such as directing, storing, transporting or distributing water. Canals are widely used in areas such as agricultural irrigation, drinking water supply, industrial processes, flood control and hydroelectric power generation. These structures contribute to the effective and efficient management of water resources (Vanani and Ostad-Ali-Askari 2022). Canals used for agricultural irrigation support food production by increasing agricultural productivity. Drinking water channels meet the water needs of cities and meet a basic need for a healthy life. Therefore, channel structures are of fundamental importance in water management and infrastructure projects.

Fig. 1. Prefabricated irrigation flume samples (URL 1; Sepetçioğlu et al. 2018).

Channel structures offer significant advantages in irrigation systems (Hunt 1988; Zhang et. al. 2019). Since they are prefabricated, construction times are short and material quality is high. In this way, long-lasting and durable structures can be obtained with a quick assembly process. Additionally, it is easy to maintain and repair, reducing operating costs. Since channel structures are built on piers at a certain height from the ground, they are almost unaffected by surface flows. This increases irrigation efficiency and ensures that water reaches the plants directly. Since their sealing properties are higher, they can be transported and reused. Routes can be easily changed by disassembly, which provides flexibility. Since the water level is kept high thanks to the feet, it provides ease of irrigation and there is no need for sockets. In addition, channel structures take up little space, which reduces their costs. Since the legs are high enough, it prevents weeds from growing. Additionally, the small water surface reduces evaporation and increases irrigation efficiency. As a result, channel structures offer many advantages such as fast installation, low maintenance costs, durability, flexibility and increased irrigation efficiency. These structures increase agricultural productivity and support the sustainable use of water resources by ensuring the effective and efficient use of water.

Canal irrigation networks may encounter some disadvantages in some cases. Canals may not be economical, especially if the irrigation area requires deep drainage. Excavation soils from drainage channels cannot be utilized because there are no tertiary channels, and this may cause additional costs. The number of flumes required for small irrigation fields may not be economical, and remote material transportation may also increase costs. Level errors may occur during construction, which may cause overflows to occur. Additionally, even a single canal falling or breaking along the canal line can cause irrigation to be interrupted or disrupted. Construction costs increase on sloping lands, which increases the cost of canal irrigation networks. This may lead to additional costs compared to piped irrigation networks. Flume irrigation networks can also be difficult to maintain and repair, which can increase operating costs. Therefore, depending on the irrigation needs and the structure of the land, alternative irrigation methods should also be considered (Sepetçioğlu et al. 2018).

Damages to flume structures are problems that may occur due to various factors. Physical breaking or damage to drains can reduce the efficiency of the irrigation system (Fig. 2). These fractures can be caused by a variety of reasons, such as ground movements, overloading, root pressure or natural disasters. Water leaks may occur at the junctions of drains or structural weak points. These leaks can cause loss of irrigation water and environmental erosion. Mud, sediment or plant debris accumulating in drains can cause blockages. These blockages block the flow of water and can render the irrigation system ineffective. Drains losing their slope over time can make it difficult to keep the water at the desired level. This can reduce irrigation efficiency and cause inadequate water delivery. Drains require regular maintenance. Mud, sediment or plant residues accumulated on the surface should be cleaned and structural damages should be corrected. Otherwise, the performance of the channels may decrease and the irrigation system may become inefficient. In addition, channel structures may be affected by various natural disasters, which may cause various damages. Sewer structures may face floods due to heavy rains. Excessive pressure of high flow water on the channel may cause cracks or erosion on the channel walls due to the corrosive effect of the water. Earthquakes can cause serious damage to channel structures. Cracks, bending or ruptures may occur in the channels due to ground shifts or direct structural weaknesses. Heavy rains or floods can cause landslides in the soil around canal structures. This can weaken the supports of the channel piers, damaging the structure. In cold climates, the freezing-thawing cycle of water in channel structures can cause expansion and contraction in the structural elements. This may cause cracks to form in the channel walls and deteriorate structural integrity. Severe storms and hurricanes can directly damage channel structures. The pressure applied to the channel walls due to the intensity of the wind may cause damage or dislocation of the channel elements. Flooding resulting from heavy rains or overflow of water resources can cause serious effects on channel structures. A sudden increase in water height can cause erosion, erosion and collapse of channel walls. Channel designs that are resistant to these natural disasters can ensure less damage to structures. Regular maintenance, damage assessment and strengthening works can also increase the durability of channel structures and strengthen their resistance to natural disasters (Sepetçioğlu et al. 2018).

Fig. 2. Damages occurring in various irrigation channel:
(a) Manisa; (b) Hasandede/Kırıkkale; (c) Kahramanmaraş (URL 2; URL 3).

Canal irrigation networks are prefabricated channels and generally consist of saddles, foundations and foundation blocks. Farmers irrigate through portable siphons placed inside the sewers. In canalized irrigation networks, there are no drainage tertiaries in the classical system. However, the drainage backup and main drainage channel are also planned according to the same principles. It consists of main structural elements such as channel, prefabricated flooring, retaining saddle, foundation and foundation block (Fig. 3.). These channels are placed on prefabricated legs of different heights, and the water is kept at the desired level by changing the foot heights (Xiao and Wu 2022).

Channel structures have an important place in irrigation systems and are important structural elements that ensure the effective distribution of water. These structures are of critical importance for irrigation of agricultural areas and management of water resources. Nowadays, studies on these structures are becoming increasingly important. Bayramoğlu (2006) aimed to select an economically and technically suitable network in the Küre-Katlıç, Selbüküköy and Gemiciköy regions of the Central Sakarya Basin Irrigation by DSI (Republic of Türkiye, General Directorate of State Hydraulic Works). In his study, he discussed the importance of channel structures and their intended use in social and economic terms. The suitability of the network systems chosen instead of these systems with today's technology was examined. Aydoğdu (2006), in his study on the evaluation of water resources and irrigation-drainage systems, presented suggestions on management and business issues that will ensure optimum use of resources, institutional and legal contents, social and cultural behaviors, environmental interaction potential, financial and economic needs. He compared other irrigation systems and talked about the advantages and disadvantages of flume structures. Sarı (2010) discussed the Balıkesir and Gönen Plains Irrigation in Balıkesir province in his thesis study. The data from the flume structures between 2005 and 2009 were evaluated using the linear regression analysis method, and the problems encountered during operation and irrigation efficiency were examined. Aydoğdu and Yenigün (2008) conducted a comprehensive evaluation of irrigation systems and drainage requirements in projects within the Euphrates and Tigris basins. Their assessment focused on analyzing water resources, irrigation systems, and water distribution methods based on collected data and field observations. Additionally, they identified water control structures and drainage needs.

Furthermore, recommendations were provided to ensure efficient water usage, detect potential operational issues, and prevent similar problems in future projects. These recommendations encompass management and operational strategies to optimize resource utilization, institutional and legal regulations, social and cultural factors, environmental interaction potentials, and economic requirements.

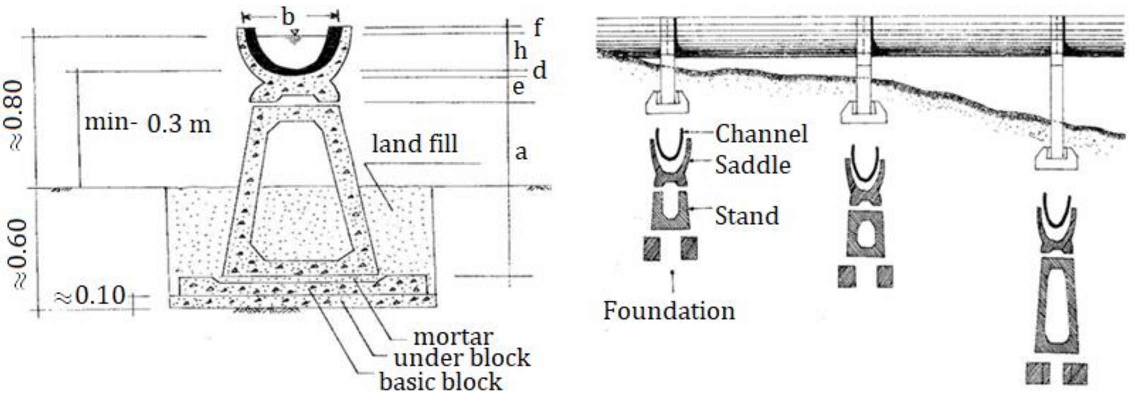

Fig. 3. Figure definition: (a) Schematic representation of flume system cross-section; (b) Flume system parts and on-site assembly situation (URL 5).

In this study, studies were carried out using the Coupled Euler-Lagrangian approach to evaluate the seismic responses of channel systems. This approach best represents the fluid-structure interaction and has features not found in other models. For example, it allows the observation of situations such as shaking of the water in the channel, possible overflow and spillage. Material models adapted to different duct units were used in the study. Three different models were analysed using the destructive earthquake record and the results were compared. These studies can be considered as an important step towards improving the seismic performance of channel structures and increasing their safety.

2. Coupled Eularian-Lagrangian Analysis for Prefabricated Flume-Fluid Interaction

The Eulerian approach tracks how variables (e.g. velocity, pressure, or temperature) change at a point in the flow at a given time. This approach describes the flow at a specific point and observes the variables at that point over time. In contrast, the Lagrangian description follows the motion of individual particles or elements of a material. With the Lagrangian approach, the motion of a particle (or element) is monitored at a given time and the properties associated with this particle are formulated considering the position and speed of the particle in motion. These two approaches are different but complementary methods for analysing the behaviour of flow (Skrzat 2012). The Coupled Euler-Lagrange approach is a method used in research to study complex interactions and is often used in research on the design, safety and sustainability of water structures and in risk analysis. This method helps make informed decisions regarding the safety, integrity, and risk assessment of structures by considering both the broad spatial context and the behaviour of individual elements (Şermet et al. 2024; Zwick and Balachandar 2020; Martin et al. 2020).

$$\text{Conservation of mass} \quad : \frac{D\rho}{Dt} + \rho \nabla . u = 0 \tag{1}$$

$$\text{Conservation of momentum} \quad : \rho \frac{Du}{Dt} + \nabla . \sigma + \rho\beta \tag{2}$$

$$\text{Conservation of energy} \quad : \frac{D\epsilon}{Dt} = \sigma : D \tag{3}$$

Here, u is the velocity vector, ρ is the density, σ is the Cauchy stress, β is the body force and e is the rate of internal energy per unit volume. The D/Dt operator is the material derivative operator defined by Eq. (4).

$$\frac{D\psi}{Dt} = \frac{\partial\psi}{\partial t} + u . \nabla\psi \tag{4}$$

The ψ in the equation represents an arbitrarily chosen physical quantity. $\nabla$is a vector and differential operator and is expressed in Cartesian and cylindrical coordinates, respectively, as follows.

$$\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \tag{5}$$

$$\nabla = e_r \frac{\partial}{\partial r} + e_\theta \frac{\partial}{\partial y} + e_z \frac{\partial}{\partial z} \quad (6)$$

$\{x, y, z\}$ in Eq. (5) represents Cartesian coordinates, and $\{i, j, k\}$ represents the unit vectors of these coordinates. $\{r, \theta, z\}$ used in Eq. (6) represents cylindrical coordinates, and $\{r, \theta, z\}$ represents the unit vectors of cylindrical coordinates. The general equation of the Euler approximation obtained by using Eq. (5) in the conservation equations:

$$\frac{\partial \psi}{\partial t} + \nabla.\varphi = S \quad (7)$$

It is in the form. φ used in the equation: flow function, S: source term (Benson and Okazawa 2004; Zhang and Zhang 2014).

3. Linear Dynamic Analysis of Prefabricated Irrigation Channel

In this study, a three-dimensional model was built to examine the turbulence occurring during the transverse ground movement of the prefabricated flumes that provide irrigation to the Manisa plain in the central Gediz Basin within the scope of the Demirköprü Dam Irrigation project. The construction of Demirköprü and the hydroelectric power plant started in 1954 and was completed in 1960. The installed power of the power plant, which consists of three units of 23 MW each, is 69 MW. The annual electricity production capacity of the power plant is 193 million kWh. By producing energy, the water coming out of the turbines is taken into channels from the Adala Regulator, approximately 1 km southwest, to irrigate 25000 ha of Adala, 65000 ha of Ahmetli and 22000 ha of Menemen (Gündoğdu and Kocataş, 2006; Güner et al., 2016).

Macro modelling was done in this study. The flume capacity is modelled as 200 lt/h. Flow speed: V = 1 m/s, cross-section wet area: A = 0.2 m^2, air share: f = 0.2 m, length: L = 5.0 m, water depth: h = 0.5 m, water surface width: b = 0.5 m (Fig. 4).

3.1. Material properties

The concrete flume material was chosen as C20 class and 0.05 m thick concrete. The linear material properties for concrete, steel, and water are provided in Table 1. Mechanical properties of concrete, steel and water were taken from the specified sources in accordance with the literature (Lin and Wu 2016; Yiğit et al. 2019; Yıldızel et al. 2014; Yıldızel 2020; Yılmaz 2023; URL 6).

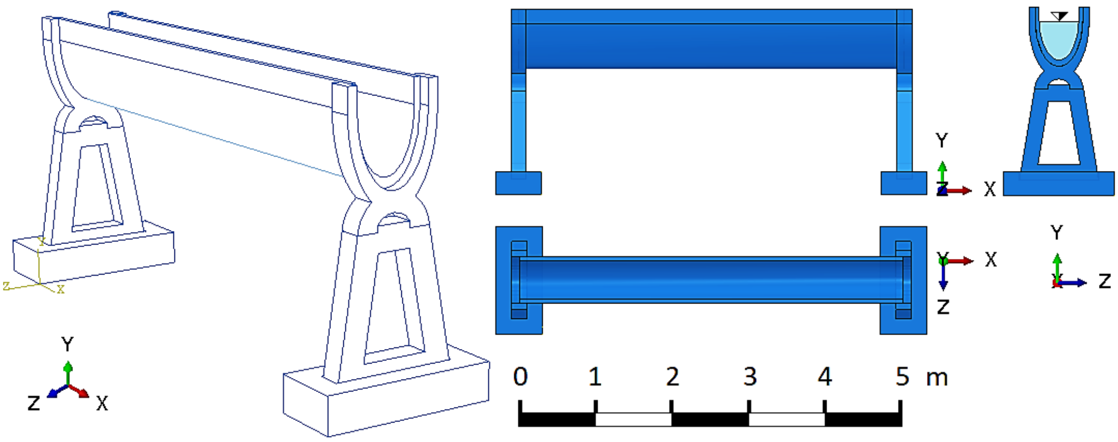

Fig. 4. Schematic representation of the flume.

Table 1. Concrete, steel and water material properties.

Material	Density (kg/m^3)	Modulus of elasticity (MPa)	Poisson's ratio	Speed of sound (m/s)	Dynamic viscosity (N.s/m^2)
Concrete	2374	28000	0.2	-	-
Steel	7834	210000	0.2	-	-
Water	1000	2200 (Bulk)	-	1450	1.002x10^{-3}

3.2. Flume finite element model

The flume three-dimensional solid model and finite element model (FEM) were created using the ABAQUS software (ABAQUS 2010) (Fig. 5). In the analysis, an explicit dynamic analysis was conducted using the software. This type of analysis is characterized by its consideration of time-dependent and transient effects, where the response of the structure is computed over small time increments. This approach is particularly suitable for modeling scenarios with rapid changes in loading conditions, such as seismic events or fluid structure interaction.

In our study, in ABAQUS enabled us to accurately capture the behavior of the irrigation canal under seismic forces and evaluate its response in detail. In creating the

FEM, a four-node triangular prism element (C3D4) (Fig. 6a) was used for the foundation structure, and an eight-node reduced integration cubic element (C3D8R) (Fig. 6b.) was used for the foot, saddle, channel and liquid. For reinforcement, two-point linear bar (B31) element type was used (Fig. 6c.). In the finite element analysis program, the interaction between the fluid and the structural elements was selected as a hard contact surface that can transfer pressure in the normal direction, and as a frictional contact surface in the tangential direction. The friction coefficient between the fluid and the structure is accepted as 0.03. The mesh spacing to be used in the FEM analysis of the channel was chosen as 0.05 m (Fig. 5b). The results of the analysis using the specified network range are given under the heading "Results". 10892 solid elements and 23252 node points were used in the waterless model, and 66948 solid elements and 84449 nodal points were used in the aqueous model. As a boundary condition, earthquake acceleration $A_X = A_Y = 0$ in the X and Y directions and $A_Z = acc(t)$ in the Z direction were entered at the base. On the sides, $U_x = 0$ was entered only in the X direction. Gravitational acceleration was entered as -9.81 m/s² in the Y direction.

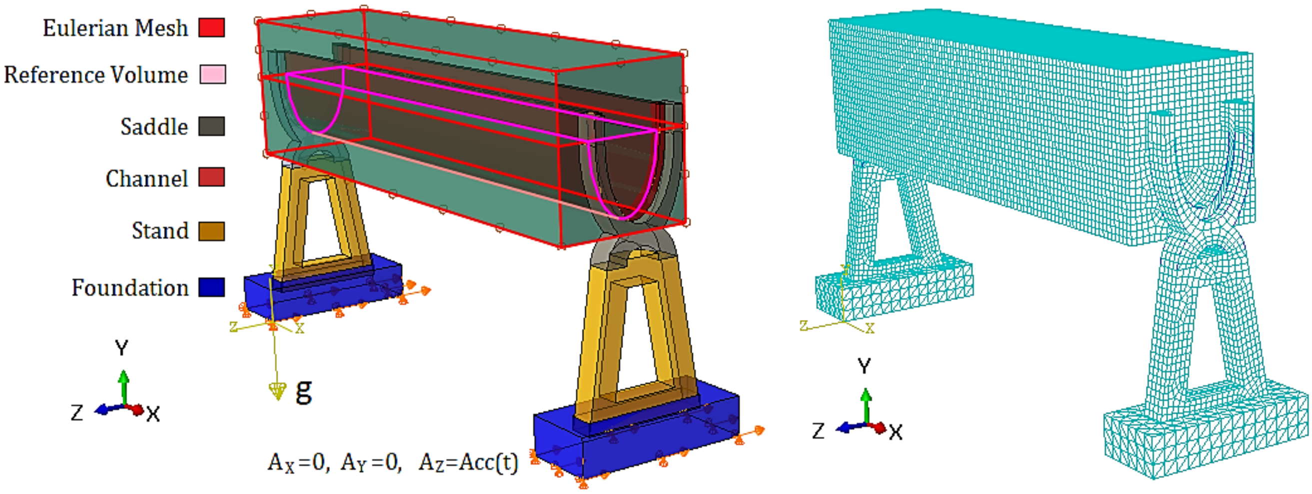

Fig. 5. Flume three-dimensional solid model and finite element mesh.

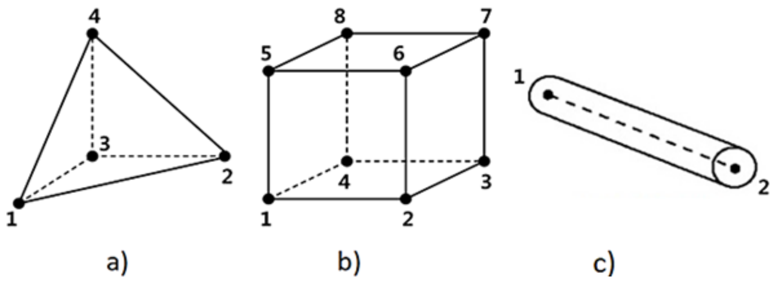

Fig. 6. (a) C3D4 triangular prism structural element; (b) C3D8R cube fluid element; (c) B31 linear rod element (ABAQUS 2010).

3.3. Seismic records used

The ground motions corresponding to the main and aftershocks of the earthquakes that occurred in Kahramanmaraş on February 6, 2023, were recorded at several stations operated by Tadas/AFAD. The latitude is 37.4851, the longitude is 37.2978, Vs30 (m/s) is 671, the soil class is ZC, and the effective duration is E-W: 24.07 s, N-S: 23.16 s, U-D: 20.81 s. The distance (Repi) is 61.30 km, and the magnitude (Mw) is 7.7 for the Kahramanmaraş-Pazarcık earthquake. The highest ground acceleration value recorded during this earthquake was at station 4614 in Pazarcık district of Kahramanmaraş province. The value measured in the East-West (E-W) component of the recording was 2.005g, while the North-South (N-S) component was 1.987g, and the vertical (U-D) component was 1.379g. In this study, to observe the fluid's agitation more clearly, the North-South direction, which caused the maximum displacement (approximately 0.23 m), is depicted in Fig. 7 with acceleration-time and spectrum graphs (Tadas 2023). To shorten the analysis time, values of the acceleration record between t=30s and t=70s were used.

4. Results and Discussion

The analysis results are presented in three different sections. The first section illustrates the surface shapes of water at different time intervals, showing the agitation of the fluid under the earthquake effect. The second section includes displacement-time graphs of the canal's peak points and the contour diagram depicting the maximum relative displacement of the canal. The third section consists of graphs showing the maximum principal tensile-time and maximum principal pressure-time at selected points from the region where the main canal is most stressed, along with contour diagrams corresponding to the maximum stresses of the main canal.

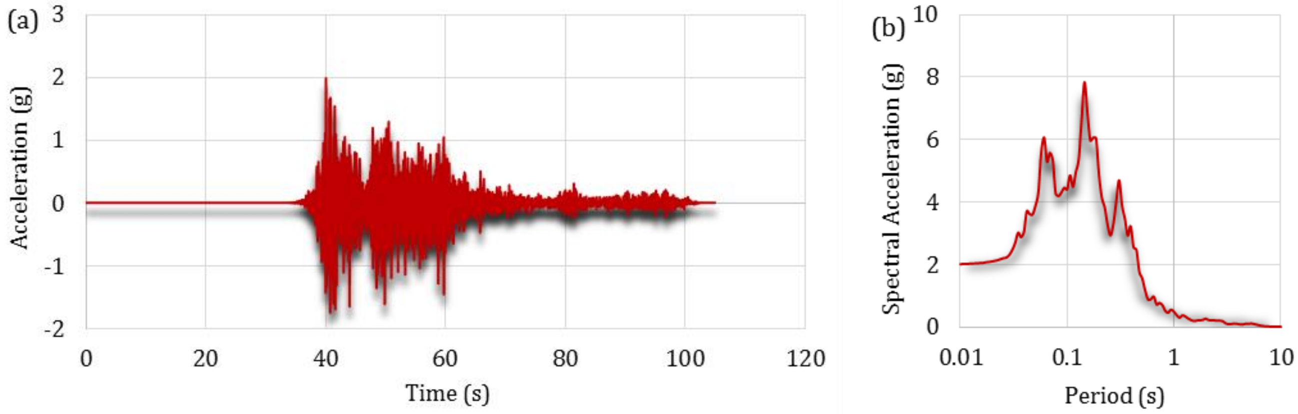

Fig. 7. North-South component of the 06/02/2023 Pazarcık/Maraş earthquake: (a) Acceleration-time graph; (b) Spectral acceleration - Period graph.

4.1. Flume surface sloshing

As a result of the sloshing, water surface shapes are magnified by a factor of 5 in the *y-y* direction for different time intervals, as shown in Fig. 8. Upon examining the model, it is observed that the water mass in the canal (shown in blue) has been set in motion and agitated under the earthquake effect. The distance between the wave crest and the wave trough, resulting from this agitation, is measured to be approximately 0.29 meters. The wave height amounted to approximately 58% of the initial water height (h=0.50 meters). The total water rise relative to the calm water level is approximately 0.19 meters. This rise accounts for about 40% of the initial water height. It is observed that the previously determined air gap for the canal (0.20 meters) is sufficient.

Since there is no partition wall or porous diaphragm restricting the movement between the fluid and the canal walls in the model, the fluid moves as a whole. Under the earthquake effect, the fluid collides with the canal walls and returns as a whole. This could lead to an increase in the height of the sloshing and overflow outside the canal. These results are consistent with the findings obtained in the literature mentioned in the articles.

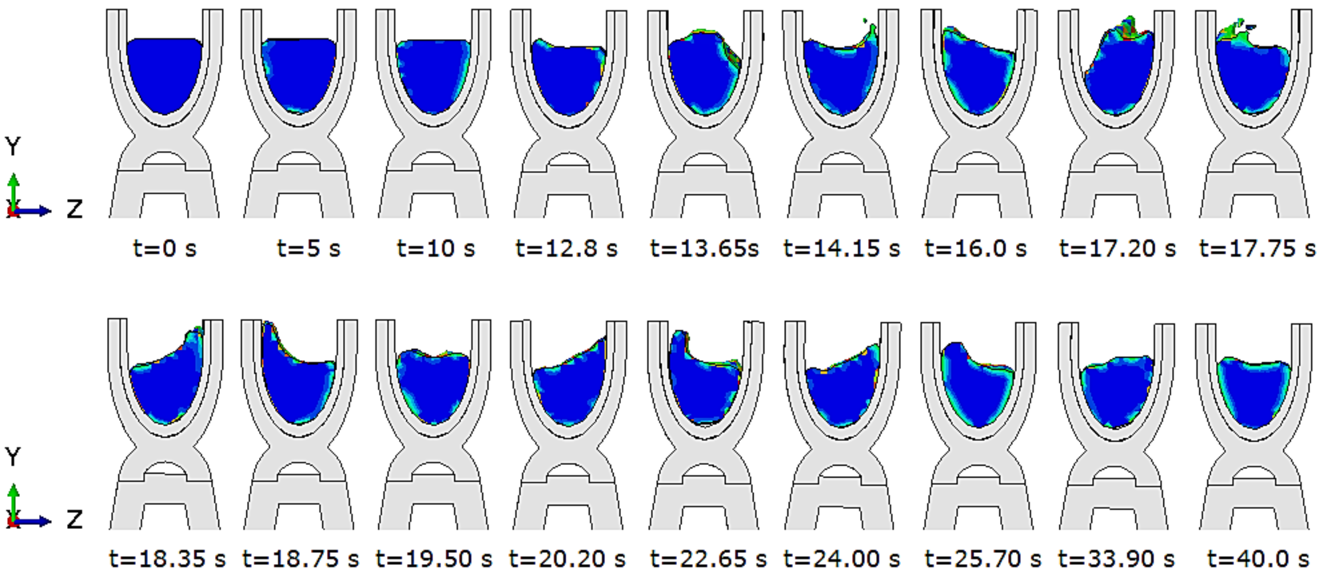

Fig. 8. Fluid sloshing surface shapes (CEL model).

Since there is no partition wall or porous diaphragm restricting the movement between the fluid and the canal walls in the model, the fluid moves as a whole. Under the earthquake effect, the fluid collides with the canal walls and returns as a whole. This could lead to an increase in the height of the sloshing and overflow outside the canal. These results are consistent with the findings obtained in the literature mentioned in the articles.

4.2. Displacements

The relative displacement between the top of the flume system and the base in the direction of the earthquake is shown in Fig. 10 as a displacement-time graph.

When Fig. 10 is examined, the maximum relative displacement value at the peak in the empty flume model is 0.087 m, while it is measured as 0.050 m in the water-filled model. The largest relative displacement contour diagrams of both models are given in Fig. 11. As can be seen, the relative displacement in the water-filled model is 42% less than in the empty model. The damping effect of water reduced the horizontal relative displacement values.

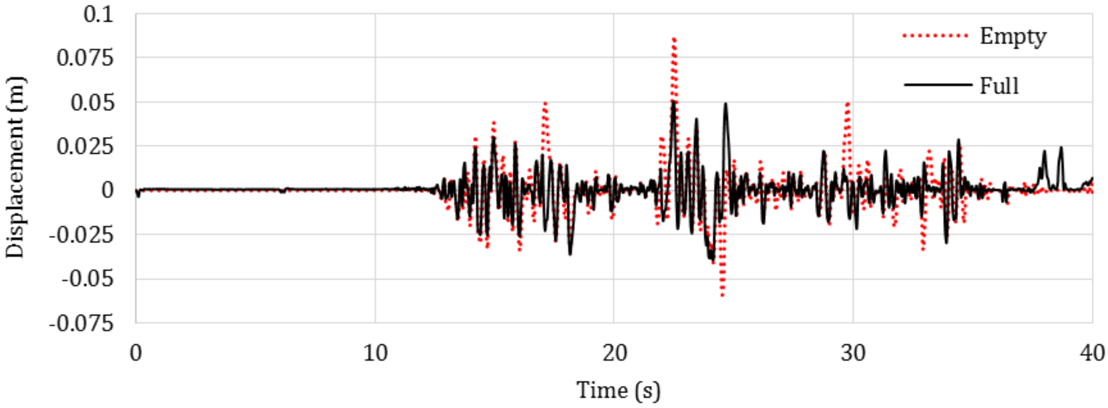

Fig. 9. Flume system peak relative displacement-time graph at upper level.

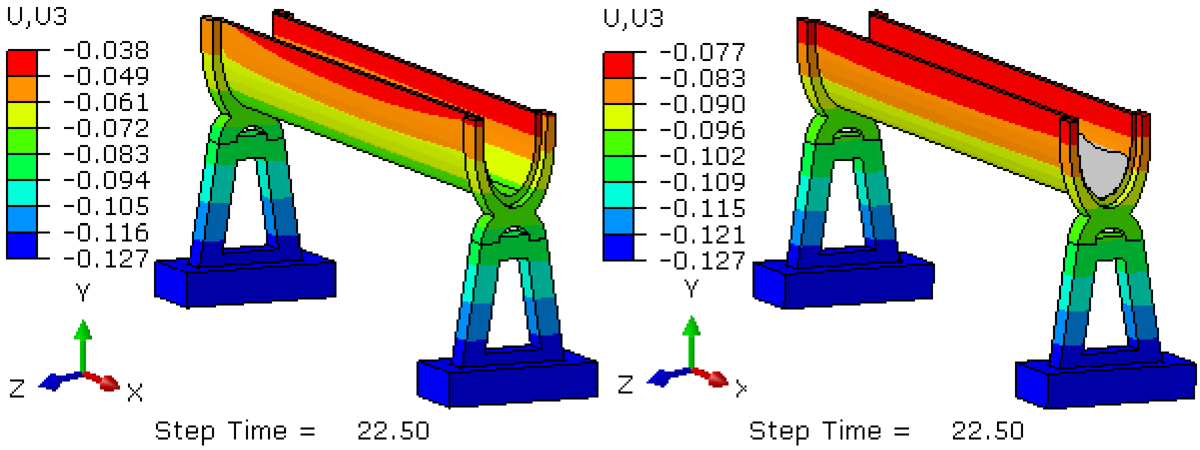

Fig. 10. Maximum relative displacement contour diagrams (m): (a) Flume system empty; (b) Flume system full.

4.3. Stresses

It was predicted that the presence of fluid in the water-filled model would cause an increase in the largest principal tensile stresses and the largest principal compressive stresses. Maximum principal tensile stress-time graphs (S_{max}) are given in Fig. 11 and maximum principal tensile stress contour diagrams are given in Fig. 12. As seen in Figs. 11 and 12, the largest principal tensile stresses increased as follows 49% when comparing the empty model with the water-filled model. In addition, in the static situation before the earthquake, the largest principal tensile stresses were measured as 0.48 MPa and 1.42 MPa in the empty and full models, respectively. These values increased to 6.82 MPa and 10.22 MPa due to dynamic effects at the time of the earthquake. This means an increase of approximately 13 times in the empty model and 7 times in the full model. The damping effect of the water in the channel limited the increase in the stress value.

Maximum principal compressive stresses-time graphs (S_{min}) and contour diagrams of the greatest principal compressive stresses are given in Figs. 13 and 14. Compared to the empty model, it was observed that the maximum principal compressive stresses increased by 75% in the water-filled model. The largest principal compressive stresses were lowest in the empty model without the additional weight of the fluid. In addition, in the static situation before the earthquake, the largest principal tensile stresses were measured as -0.45 MPa and -1.04 MPa in the empty and full models, respectively. These values increased to -4.98 MPa and -8.61 MPa due to dynamic effects at the time of the earthquake. This means an increase of approximately 11 times in the empty model and 8 times in the full model. The damping effect of the water in the channel limited the increase in the stress value.

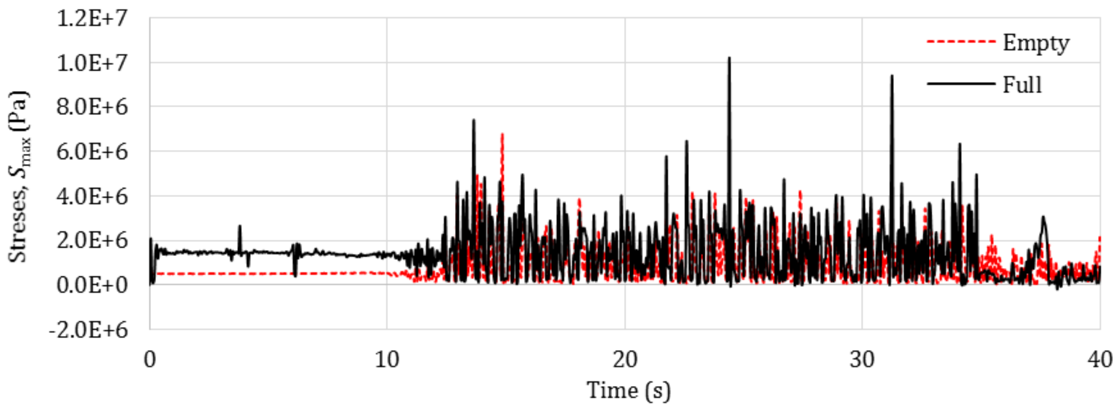

Fig. 11. Maximum principal tensile stress-time graphs (S_{max}).

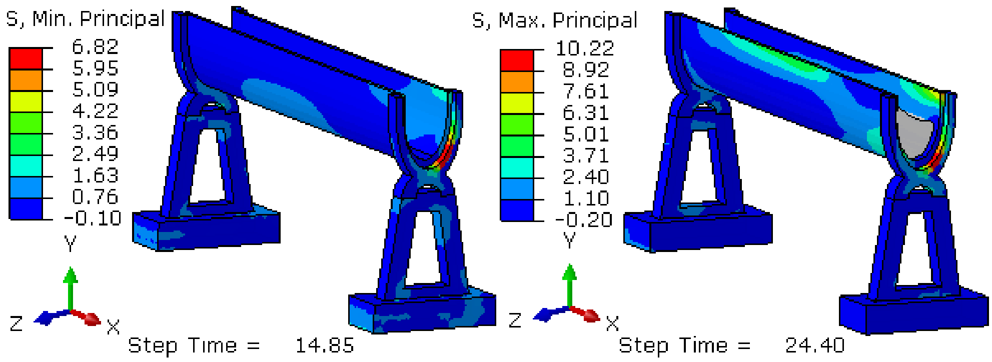

Fig. 12. Maximum principal tensile stress contour diagrams (MPa):
(a) Flume system empty; (b) Flume system full.

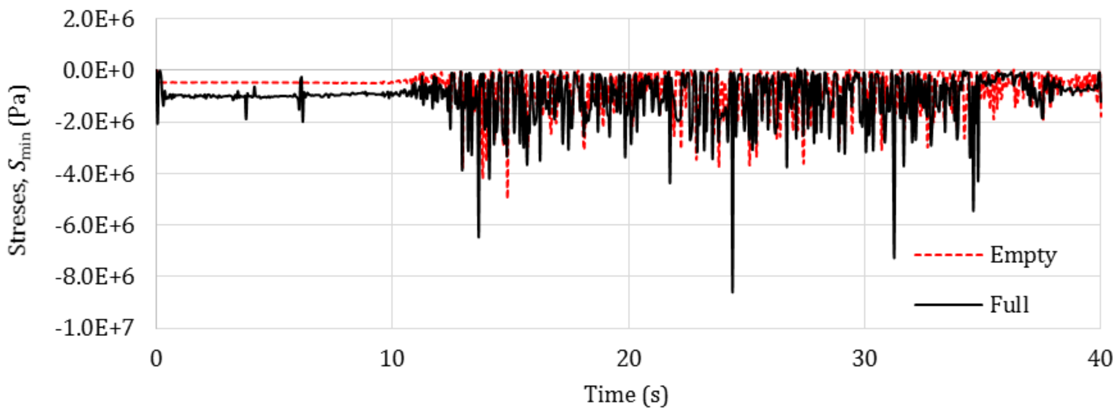

Fig. 13. Maximum principal compressive stress-time graphs (S_{min}).

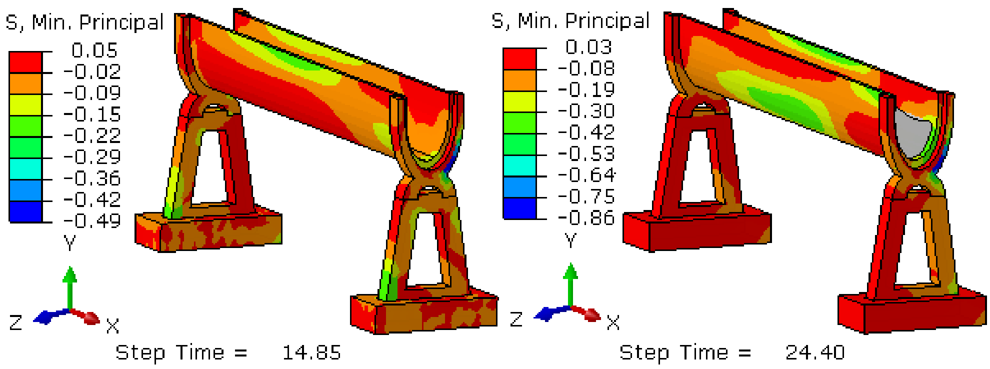

Fig. 14. Maximum principal compressive stress contour diagrams (MPa):
(a) Flume system empty; (b) Flume system full.

5. Conclusions

In this study, dynamic analysis was carried out to investigate the seismic responses of a prefabricated irrigation canal in its empty and full state. To see the devastating earthquake effects, the North-South record of the 06/02/2023 Pazarcık/Kahramanmaraş earthquake with a Peak Ground Acceleration (PGA) value of approximately 2.0g was used. Water was used as the fluid in the main irrigation channel, the material properties and dimensions of which were taken from the literature. As a result of the analysis, the following results were obtained.

- It has been observed that water turbulence shows earthquake effects with the Coupled Eularian-Lagrangian (CEL) approach. By analysing the models, shaking and possible water overflow during an earthquake could be easily observed.
- During devastating earthquakes, the value between the sloshing peak and trough of the water mass in the prefabricated irrigation canal was approximately 58% of the initial water level, and the water rise was 40% of the initial water level.
- Considering the fluid-structure interaction, relative displacements in the filled model decreased by 42% compared to the empty model.
- The sloshing effect and liquid weight caused an increase of 49% and 75% in the maximum principal tensile stresses ($S_{\max}$) and the maximum principal compressive stresses ($S_{\min}$), respectively.
- In the absence of water, dynamic effects increased the maximum principal compressive stresses by 13 times and the maximum principal tensile stresses by 11 times compared to the pre-earthquake. In the case of water, these increases were 7 times and 8 times, respectively. The damping property of the fluid showed its effect in the case of water.

In all models, the largest principal compressive stress distributions and the largest principal tensile stress distributions are concentrated in an area close to the junction of the base and slope, where the flume is usually damaged in earthquakes.

Future studies that can be done on this subject are listed below as suggestions.

- Prefabricated irrigation channels have different sizes for different flow rates. For this reason, the issue of determining the most appropriate water height and air share under seismic effects can be investigated.
- Fluid-structure interaction seismic analyses can be performed for earthquakes with different PGA(g) values and the results can be compared.
- Comparative analysis can be conducted with different fluid-structure interaction models.
- Analyses can be performed for various fill levels, and the results can be compared.
- The damage situation can be examined in detail by performing nonlinear dynamic analysis of the same structure.

Analyses have shown how the seismic effects of the prefabricated irrigation canal can occur in empty and full situations. For this reason, it is recommended that dynamic calculations and sloshing analysis, as well as static and hydraulic calculations of the main channels, be made by considering the fluid-structure interaction. Thus, floods can be prevented in case of possible earthquakes.

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Conflict of Interest

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Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

References

ABAQUS (2010). ABAQUS user's manual, Version 6.10. Dassault Systèmes, SIMULIA.

AFAD (2023). İçişleri Bakanlığı "Afet ve Acil Durum Daire Başkanlığı". [Online]. Available: https://deprem.afad.gov.tr/content/131

Angelakıs AN, Zaccaria D, Krasilnikoff J, Salgot M, Bazza M, Roccaro P, Jimenez B, Kumar A, Yinghua W, Baba A, Harrison JA, Garduno-Jimenez A, Fereres E (2020). Irrigation of world agricultural lands: Evolution through the millennia. *Water*, 12(5), Article 5.

Aydoğdu MH (2006). Evaulation of Water Resources and Irrigation-Drainage Systems of GAP, Southeastern Anatolia Project. *Thesis*, Harran University, Şanlıurfa, Türkiye.

Bayramoğlu E, (2006). Orta Sakarya Havzası Sulama Sahalarındaki Bazı Sulama Hatlarında Dağıtım Şebekesi Seçimi ve Karşılaştırmalı Ekonomik Analizleriyle İlgili bir Çalışma. *M.Sc. thesis*, Anadolu University, Eskişehir, Türkiye.

Benson DJ, Okazawa S (2004). Contact in a multi-material Eulerian finite element formulation. *Computer Methods in Applied Mechanics and Engineering*, 193, 39, 4277–4298.

Canbaz M, Kara İ, Topçu İB (2021). Effect of high temperature on the mechanical behavior of cement-bonded wood composite produced with wood waste. *Challenge Journal of Structural Mechanics*, 7(1), 42-48.

Cosgrove WJ, Loucks DP (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, 51(6), 4823–4839.

Ertsen MW (2010). Structuring properties of irrigation systems: Understanding relations between humans and hydraulics through modeling. *Water History*, 2(2), 165–183.

Gündoğdu V, Kocataş A (2006). Gediz Nehir Havzası Yönetim Planı Oluşturulmasına Yönelik Bir Yaklaşım. *E.U. Journal of Fisheries & Aquatic Sciences*, 23(3-4), 371–378, ISSN 1300 - 1590.

Güner S, Yılmaz OS, Erbaş YS, Gümüş E, Güngör R, Şahbaz K (2016). Demirköprü Barajı'nın Su Kotu Seviyesine göre Arazi Kullanilabilirlik Analizi. *6. Uzaktan Algılama-CBS Sempozyumu* (UZAL-CBS 2016), 5-7 October, Adana, Türkiye.

Hunt RC (1988). Size and the structure of authority in canal irrigation systems. *Journal of Anthropological Research*, 44(4), 335–355.

Jury WA, Vaux HJ (2007). The emerging global water crisis: managing scarcity and conflict between water users. *Advances in Agronomy*, 95, 1–76.

Lin J, Wu Y (2016). Numerical analysis of interfacial bond behavior of externally bonded FRP-to-concrete joints. *Journal of Composites for Construction*, 20, 04016028.

Martin T, Kamath A, Bihs H (2020). A Lagrangian approach for the coupled simulation of fixed net structures in a Eulerian fluid model. *Journal of Fluids and Structures*, 94, 102962.

Özbek T (1987). Sulama Kurutma. Gazi Üniversitesi, Ankara, Türkiye.

Pedro-Monzonís M, Solera A, Ferrer J, Estrela T, Paredes-Arquiola J (2015). A review of water scarcity and drought indexes in water resources planning and management. *Journal of Hydrology*, 527, 482–493.

Sarı T (2010). Balıkesir ve Gönen Ovaları Sulama Sistemlerinin Performanslarının İncelenmesi. *M.Sc. Thesis*, Balıkesir University, Balıkesir, Türkiye.

Sepetçioğlu MY, YeniGün K, Karakuş S, Aslan V (2018). Şanlıurfa ili sulamaları ışığında sulama şebekelerinin karşılaştırılması. *Turkish Journal of Hydraulics*, 2(1), 19-30.

Skrzat A (2012). Application of coupled Eulerian-Lagrangian approach in metal forming simulations. *Mechanika*, 84(4), 25–35.

Sophocleous M (2004). Global and regional water availability and demand: Prospects for the future. *Natural Resources Research*, 13(2), 61–75.

Şermet F, Kartal ME, Yiğit ME, Hökelekli E (2024). The effect of the gravity on the earthquake performance of roller compacted concrete dams. *Challenge Journal of Concrete Research Letters*, 15(1), 20–29.

Uluöz S, Tayakısı A (2003). 1960–1966 yılları arasında üretilerek sulama şebekelerinde kullanılan prefakrik kanaletlerin 2000 yıllındaki mevcut kalitesi. *TMMOB 5. Ulusal Beton Kongresi*, 1-3 October, İstanbul, Türkiye.

URL-1: S. Özkan, Kanalet İnşaat - Kanalet Grubu [Online]. Available: http://www.kanalet.com.tr/firma/insaat

URL-2: News: Lağım Suyu Değil DSİ'ye Ait Sulama Kanalı - Manisa Büyükşehir Belediyesi [Online]. Available: https://www.manisa.bel.tr/Haberler/2296_lagim-suyu-degil-dsiye-ait-sulama-kanali.aspx

URL-3: News: Köyün sulama kanalı çöktü, İl Gazetesi [Online]. Available: https://www.ilgazetesi.com.tr/koyun-sulama-kanali-coktu-295475h.htm

URL-4: News: Kahramanmaraş'ta dağdan kopan kayalar 3 bin dekar araziyi sulayan kanallara zarar verdi, Anadolu Ajansı [Online]. Available: https://www.aa.com.tr/tr/asrin-felaketi/kahramanmarasta-dagdan-kopan-kayalar-3-bin-dekar-araziyi-sulayan-kanallara-zarar-verdi/2859527

URL-5: News: Su İletim ve Dağıtım Yapıları, Ankara Üniversitesi Açık Ders Malzemeleri [Online]. Available: https://acikders.ankara.edu.tr/pluginfile.php/99040/mod_resource/content/1/TSY_Blm3.pdf

URL-6: T.C. Tarım ve Orman Bakanlığı, Sulama Tesislerinde Sanat Yapıları İnşaatı Teknik Şartnamesi, 2006 [Online]. Available: https://cdniys.tarimorman.gov.tr/sulama-tesislerinde-sanat-yapılar-inşaat teknik şartnamesi.pdf

Vanani HR, Ostad-Ali-Askari K (2022). Correct path to use flumes in water resources management. *Applied Water Science*, 12(8), 187.

Xiao Z, Wu W (2022). Durability analysis of small assembled buildings in irrigation canal system. *Scientific Programming*, 2022, e2202052.

Yenigün K, Aydoğdu MH (2008). Turkiye'nin en büyük entegre su kaynakları projesi GAP'ta sulama ve drenaj sistemlerinin özet değerlendirmesi. *TMMOB*, 2, 159–174.

Yildizel SA (2020). Material properties of basalt-fiber-reinforced gypsum-based composites made with metakaolin and silica sand. *Mechanics of Composite Materials*, 56, 379-388.

Yildizel SA, Yiğit ME, Kaplan G (2017). Glass fibre reinforced concrete rebound optimization. *Computer Modeling in Engineering & Sciences*, 113(2), 203-218.

Yılmaz MC (2023). Effects of pre-cracked reinforced concrete in compression zone on prefabricated RC beam behavior. *Challenge Journal of Structural Mechanics*, 9(2) 77–83.

Yiğit ME (2019). Dalga Sediment ve Sıvılaşan Zemin İtkilerine Maruz Rıhtım Kazıklarının Dinamik Analizi. *Ph.D. thesis*, Manisa Celal Bayar University, Manisa, Türkiye.

Zhang F, Guo S, Zhang C, Guo P (2019). An interval multiobjective approach considering irrigation canal system conditions for managing irrigation water. *Journal of Cleaner Production*, 211, 293–302.

Zhang Z, Zhang HW, (2014). Solid mechanics-based Eulerian model of friction stir welding, *International Journal of Advanced Manufacturing Technology*, 72(9–12), 1647–1653.

Zwick D, Balachandar S (2020). A scalable Euler–Lagrange approach for multiphase flow simulation on spectral elements. *The International Journal of High Performance Computing Applications*, 34(3), 316-339.