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Analytical Study on Retrofitting Concrete Retaining Wall with Concrete Lining

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Abstract – Today, retaining walls are gaining importance with the developing transportation networks. Different solutions are made in the design of retaining walls according to the land structure and ground condition. Various retrofitting methods are used in damaged retaining walls. Especially in recent years, natural disasters in Turkey have also affected the retaining walls. There may be damage and collapse in the retaining walls during and after the disaster. It is predicted that in the event of a possible collapse in the event of a disaster, loss of life and property may also occur. After the disaster, even if the retaining walls have not collapsed, they are damaged. In this case, collapse may occur in the next disaster due to collapse or environmental vibrations. It is also known that in post-disaster situations, it is vital that the transportation network remains active in order to deliver the necessary aid to the region. For all these reasons, in this study, the concrete lining method, which is one of the retrofitting methods of retaining walls, is mentioned. Thus, the effect of the concrete lining method applied on an exemplary retaining wall on modal parameters has been demonstrated. In this comparative study, it was observed that the stiffness of the retaining wall increased with the concrete lining method. As a result of this study, it is suggested to retrofitting the retaining walls with the concrete lining method, taking into account the state of the wall and environmental factors.

Keywords – Concrete Retaining Wall, Concrete Lining, Modal Analysis, Retrofitting

I. INTRODUCTION

Many types of structures are damaged as a result of natural disasters (such as floods, landslides, earthquakes). According to the degree of damage received, loss of life and property occurs with the collapse. In some structures, collapse does not occur as a result of disasters, but damage is observed [1], [2], [3], [4]. Various reinforcement methods are applied in such structures. Thus, the structures are restored to their former bearing strength and stiffness, thus avoiding possible collapse. In addition to the loss of life and property that may occur with the effect of collapse in retaining walls, indirect loss of life and property is seen with the damage of transportation networks. Various proven retrofit methods are available to solve such problems. The use of concrete lining is one of these retrofit methods.

Retaining walls are elements manufactured to limit the movement of the ground under the natural slope angle. Apart from this purpose, for constructive purposes, separation of two different grounds, etc. They are used in situations. Different types of retaining structures have emerged depending on the mechanical properties of the ground. In addition to these mechanical properties, the place of use of the retaining structure to be built (coast, sea, etc.), its purpose (to ensure ground stability, to separate different soils, etc.), environmental conditions (air temperature, humidity, etc.), other nearby structures status, etc. It should be designed by considering the situations. Today, retaining walls are the most preferred retaining structures. There are many reasons why these structures are used frequently. First of all, their project is easy and fast compared to other structures. Size flexibility is unlimited compared to other building types. Many different types of materials can be used (concrete, reinforced concrete, steel, masonry, composite, etc.). They are very successful against many dynamic load types (earthquake, tsunami, blasting, etc.) apart from their main usage purposes [5], [6].

The operations performed to raise an undamaged structure or structural element to a prescribed safety level are defined as "reinforcement", and the operations performed to raise a damaged structure or structural element to a prescribed safety level are defined as "repair". Damaged structures are generally strengthened as well as repaired [7]. The expansion and enlargement process with new concrete layers and reinforcements in order to strengthen the existing reinforced concrete element is called “concrete lining”. For example; column, beam etc. Structural jacketing of structural elements is a concrete lining application. The 5.8 magnitude Istanbul earthquake on September 26, 2019 (epic center off Silivri) and the 6.8 magnitude earthquake on January 24, 2020 in Elazig (epic center in Sivrice district) increased the uneasiness in Turkey and the sensitivity to take precautions against earthquake risk. Along with this process, the need for rehabilitation and strengthening of existing structures has increased, and concrete coating application has started to gain importance and frequency of use. A new structural element section is formed by the contact of the surfaces of the old and new concrete layers. Undoubtedly, the expectation from this section is that the old and new layers act together. In other words, the cross section of the building should behave monolithic (holistic) and the contact surfaces of the concrete layers should not be separated from each other. In the Eurocode 2 standard, it is stated that the cohesion and friction in the concrete-concrete surface joint depend on the degree of surface roughness [8]. In Turkey, there is no standard or regulation that includes the design principles of the 'concrete pavement' application. As with the general attitude towards design issues that are not included in local regulations, the concrete pavement application is primarily directed to European standards.

Researchers have carried out many studies using both the retrofitting and the finite element method. Researchers have conducted studies [8], [9], [10], [11], [12], [13], [14], [15] about concrete linings which also contributed to this study. Also, researchers have conducted studies [16], [17], [18], [19], [20], [21], [22] about retaining walls which also contributed to this study.

The aim of this study is to contribute to the retrofitting of retaining walls, which are also used in transportation networks, according to their pre-disaster and post-disaster stiffness conditions. It is known that there are many retrofitting methods available for the retaining walls to regain their former stiffness. In this study, the effects of the concrete lining method on retaining wall stiffness and mode shapes are investigated.

II. Materials and Method

In this study, concrete retaining wall model was created and modal analysis was carried out with the finite element method. The concrete retaining wall model was retrofitted with concrete lining and two concrete retaining wall model was created for comparison. Variables on the model should be minimized in order to better see the reinforcement effects. Therefore, it was emphasized that the models should be designed simply and symmetrically. Thus, it is aimed that the only variable between both models is the retrofitting method. In the application of the finite element method, the SAP2000 package program, which is used in the field of academic and engineering applications all over the world, was used.

A. *Description of Concrete Retaining Wall Model*

The model retaining wall is designed as concrete. The wall is 2 m high, 6 m long, and 0.25 m thickness. The mechanical parameters of the model concrete retaining wall are; poisson's ratio: 0.2, modulus of elasticity: 30 GPa, density: 24 kN/m^3. The concrete retaining wall finite element model was created using the SAP2000 software. The finite element model of the concrete retaining wall is given in fig. 1.

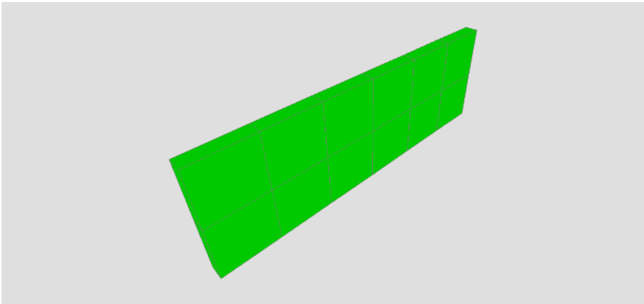

Fig. 1 3D Finite element model of the concrete retaining wall

B. *Description of Concrete Retaining Wall Retrofitted Model*

0.05 m concrete lining process was applied to the outer surface of the existing model. Mechanical properties of the applied concrete lining; poisson's ratio: 0.2, modulus of elasticity: 35 GPa, density: 24 kN/m^3.

III. Results and Discussion

Concrete retaining wall model and concrete retaining wall retrofitted model were analysed (modal) using SAP2000 software. The period and mode shapes obtained for both models are obtained for each mode.

A. *Results of Concrete Retaining Wall Model*

The modal analysis of the concrete retaining wall model was performed with FEM. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 2,3,4,5,6 as periods and mode shapes.

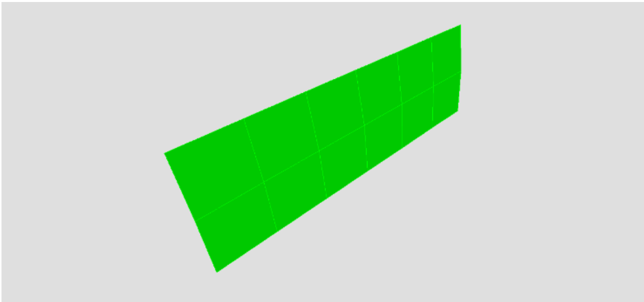

Fig. 2 Mode shape (Period value = 0.097 s)

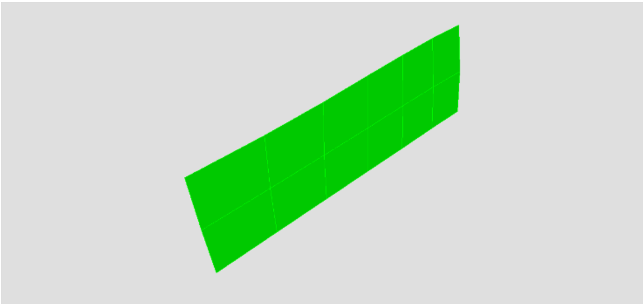

Fig. 3 Mode shape (Period value = 0.077 s)

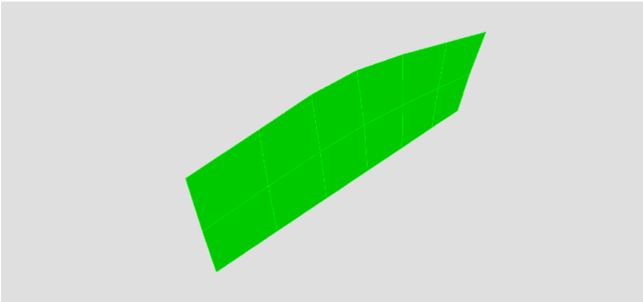

Fig. 4 Mode shape (Period value = 0.051 s)

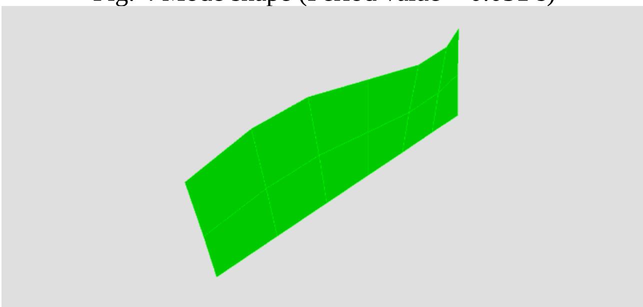

Fig. 5 Mode shape (Period value = 0.034 s)

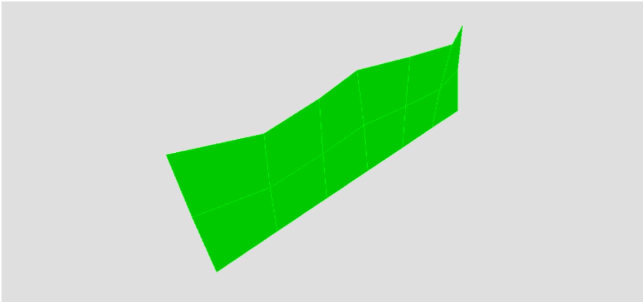

Fig. 6 Mode shape (Period value = 0.023 s)

B. *Results of Concrete Retaining Wall Retrofitted Model*

The modal analysis of the concrete retaining wall retrofitted model was performed with FEM. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 7,8,9,10,11 as periods and mode shapes.

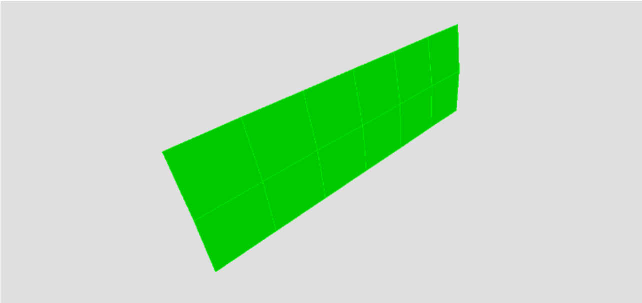

Fig. 7 Mode shape (Period value = 0.051 s)

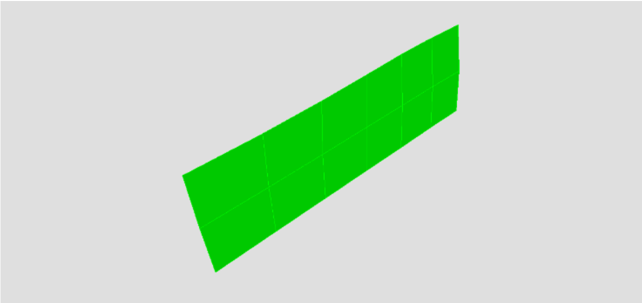

Fig. 8 Mode shape (Period value = 0.040 s)

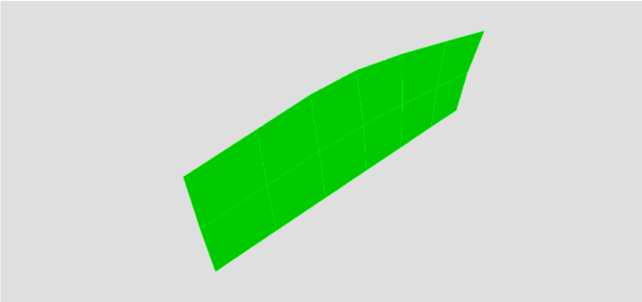

Fig. 9 Mode shape (Period value = 0.026 s)

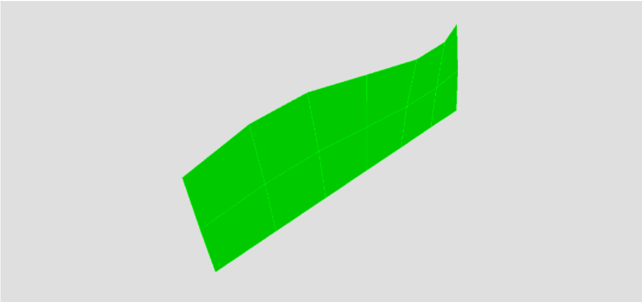

Fig. 10 Mode shape (Period value = 0.018 s)

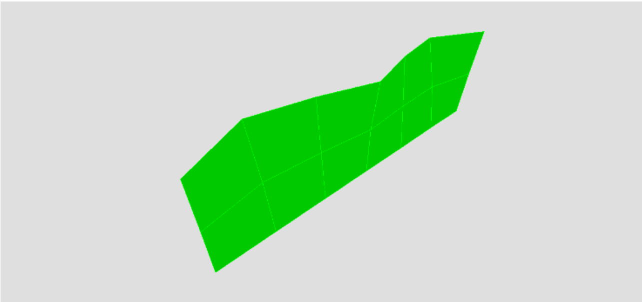

Fig. 11 Mode shape (Period value = 0.012 s)

C. *Comparison of Modal Analysis Results*

The comparison of periods of the model non-retrofitted (concrete retaining wall model) and retrofitted (concrete retaining wall retrofitted model) are given in Table 1.

Table 1. Comparison of period values

Mode	1	2	3	4	5
Non-retrofitted	0.097	0.077	0.051	0.034	0.023
Retrofitted	0.051	0.040	0.026	0.018	0.012
Difference (s)	0.056	0.037	0.025	0.016	0.011
Difference (%)	57.73	48.05	49.02	47.06	47.83

When both models are examined, no major changes were observed in the mode shapes. When the mode shapes are examined in general, translations are seen in the 1st and 2nd mode shapes in both models. Torsions dominate in the 3rd, 4th and 5th mode shapes. With the retrofitting, some reduction in translation and torsion was observed.

IV. CONCLUSION

In the mode 1, the period difference between non-retrofitted and retrofitted status was obtained as 0.056 s. The effect of period retrofitting with concrete lining as a percentage was determined as 57.73.

In the mode 2, the period difference between non-retrofitted and retrofitted status was obtained as 0.037 s. The effect of period retrofitting with concrete lining as a percentage was determined as 48.05.

In the mode 3, the period difference between non-retrofitted and retrofitted status was obtained as 0.025 s. The effect of period retrofitting with concrete lining as a percentage was determined as 49.02.

In the mode 4, the period difference between non-retrofitted and retrofitted status was obtained as 0.016 s. The effect of period retrofitting with concrete lining as a percentage was determined as 47.06.

In the mode 5, the period difference between non-retrofitted and retrofitted status was obtained as 0.011 s. The effect of period retrofitting with concrete lining as a percentage was determined as 47.83.

With the retrofitting, some reduction in translation and torsion was observed.

In the light of all these results, it is clearly seen that the stiffness of the concrete retaining wall model increases by retrofitting the concrete retaining wall model with concrete lining. In the 1st mode, in other words, there is a decrease of 57.73 percent in the dominant period value. The maximum decrease in period values was observed in the 1st mode and it is known that this is a very positive situation in terms of retrofit. As a result of this study, the concrete retaining walls can retrofit with the concrete lining method, taking into account the state of the wall and environmental factors.

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