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DECISION SELECTION TECHNIC FOR BUILDING STRENGTHENING METHODS

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ABSTRACT

Nowadays, old existing buildings with less load carrying capacity are usually strengthened by the application of a suitable strengthening method. Such methods include the use of steel bracing, FRP jacketing or wrap, concrete jacketing, steel plating, shear wall and hybrid methods. However, there are the possibilities of selecting a strengthening method without comparing for the most efficient method, due to time constraint or little knowledge about strengthening methods. These will however, lead to ignoring the differences among the strengthening methods.

In the present study, information about strengthening methods is highlighted as obtained from the survey. According to this information, decision selection program is set up, where different strengthening methods are encoded with their characteristics of solving problems. A case study is applied herewith to check the efficiency of the decision selection program. The recommended strengthening methods are ascertained to be relatively more economical, efficient and time saving.

Keywords: Strengthening; global strategy; choice selection; local strategy.

1. INTRODUCTION

Selection of a suitable strengthening method for upgrading or increasing the load carrying capacity of the existing buildings represents an important aspect of the construction industry and its significance has an up surging trend. There are numerous strengthening methods available, each of which has its own exclusive advantages and disadvantages on any building it is applied to. Therefore, in order to decide a suitable strengthening method, it is required that the problem with the building found during the assessment is investigated thoroughly, different strengthening methods are comparatively analyzed for the most

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suitable option. However, some researchers prefer to compare these methods through applying different strengthening method studies on buildings. Jinbo Li et al [1] affirm that steel jacket strengthening is not a suitable application in a marine environment as the rate of corrosion of steel appears to be very high therein. Hence, it may necessitate the use of coatings, of which process leads to an increase in the cost of the strengthening scheme. Abdullah and Katsuki [2] in their experiment, found out that, application of mortar between steel jackets and concrete structural members will have no significant effect in the increase of the performance of that structural member, if the member does not have any significant damage or crack in it. Therefore, it will only add to the cost of strengthening. Also, Eunsoo and Kim [3] in their experimental study on the use of rectangular steel jackets, deduced that the buildings of the early sixties, with inadequate seismic resistance, could be strengthened by steel jacketing, especially for columns lacking the flexural strength. According to Riyad and Jirsa [4], steel jacketing yielded a good result for the columns designed for gravity loads without any earthquake design. Regarding the comparison of steel jacketing with FRP, for strengthening the aforesaid, Leng and Teng [5] confirmed that FRP does not possess as much ductility as steel does. Therefore, this might limit the ductile related behavior of a reinforced concrete member strengthened with FRP wrap, as the seismic performance of structures depends on the ductility of the column-beam joints [6]. Amoury and Ghobarah [7] in their studies fixed that the FRP strengthening does not significantly alter the dynamic response of structural frames, but changes the damage location and pattern within the frame. They concluded that, the said does not affect the initial stiffness of structural members, but improves the strength of the member. Parvin and Wang [8] deduced through their studies that FRP strengthening could be used in delaying the degradation of stiffness of reinforced concrete columns. Furthermore, Muthuswamy and Thirugnanam [9] brought to light that FRP improves the ductility of a column-beam joint by 50 %, with energy absorption by 80 % and hence it might possibly be used in seismic regions. Badoux and Jirsa [10] also stated that steel bracing is good for frames with weak and short columns. Hasan et al [11] affirms that shear wall is effective for symmetrical buildings in seismic regions. Jinbo Li et al [1] in their experiment on a hybrid method for FRP and steel jacket, fixed that the combination is effective for structural members with corroded internal reinforcement. It gives better result than when strengthening is carried out with only FRP or steel jacket. Chintha Perera et al[12] in their work, have created map to give a decision about the best strengthening method. However, there may be variations in building problems as well as in performances in different seismic regions. For this reason, with the building problems involved within different seismic zones, there should be a selection technic where the strengthening method, seismic zones, building type and problems are considered while deciding which methods of building strengthening will be most efficient and economical.

The objective of this paper is to design a decision selection tool, which will help the users or engineers in selecting a suitable strengthening technique within a short period of time as long as the building problem requirements are necessarily applied on the proposed decision tool.

2. METHODOLOGY

Through a review of the literature, industry practices conducted in the previous strengthening projects, the issues arisen in different strengthening methods have been identified in terms of their advantages and disadvantages on various types of buildings of different shape. The effects on the buildings in different seismic zones, the costs involved with and their application targets along with the problems encountered with the old existing concrete buildings, have also been identified. The strengthening methods were grouped into different strengthening strategies such as; global, local and integrated groups. The identified building problems and strengthening methods with their advantages and disadvanges were prepared as detailed in tabular form. These strengthening method characteristics are used to construct the decision selection tool. The seismic zone accounts for the geographical location of such building to be investigated, while strengthening strategy accounts for the amount of strengthening that may be required by the building under investigation. All the building problems as found in old existing buildings are encoded into the strengthening methods as highly applicable or not applicable. The values realized by each strengthening method can be used to judge its suitability for use in any strengthening investigation carried out. This can be seen clearly in the proposition and relevance counts in the decision selection tool. The characteristics of the studied strengthening methods and their application targets are detailed in Table 1 and Table 2.

Other methods such as; combinations of different strengthening methods or hybrid methods, are detailed in the Table 3 while the strengthening strategies will be discussed further.

Table 1: Strengthening methods, Characteristics and Application Targets

Strengthening options	Steel Jacketing
Characteristics	• The strength of the jacket depends on the welding condition between the split jackets. • Limited enhancement of flexural strength. • It improves flexural and shear strength. • It requires no grout for application for an existing new building without degradation. • It improves the stiffness, ductility and axial load carrying capacity.
Application targets	• For passive confinement. • To strengthen members with a deficiency in transverse reinforcement. • For members with low concrete grade.
Application areas	• Columns. • Beams.
Demerits	• Not suitable for corroded RC at marine environment. • Because it is not anchored to the foundation, it does not provide maximum flexural confinement. • Not good for axial load enhancement when there are gaps at the beginning and end applications on a member (25mm to 50mm). • It may add weight to the structure.

Characteristics	• For flexural and shear strength improvement. • It can be bonded to the surface with epoxy and anchors. • No significant improvement with the application of steel plate with very low concrete grade. • Failure mode when applied with adhesive is premature debonding. With bolts are ductile failure.
Application target	• Applied to the side surface to improve shear strength and tension surface to improve flexural strength.
Application areas	• Columns. • Beams. • Slabs.
Demerits	• It is not safe to apply onto a deteriorated concrete member. • There are difficulties in joining two plates by butt-welded joint in the site.
Characteristics	• It is an inexpensive method. • It involves concrete jacketing of members. • In severe weather conditions, there could be a possible corrosion of the internal reinforcement.
Application targets	• Load capacity and stiffness can be increased. • Increases the stiffness of structures. • Improves the weak column with strong beam. • To correct mistakes of transverse reinforcement.
Application areas	• Columns, beams, slabs. • Walls. • Foundations.
Demerits	• Holes created for anchoring is not proper for members that are small in size or have a poor concrete grade. • There could be a disturbance of the use of the building during strengthening.

Table 2: Strengthening methods, Characteristics and Application Targets

Strengthening options	Shear Walls
Characteristics	• It is a good application for symmetrical building. • Correct discontinuity in building structures. • It is effective in buildings with flat slab. • It is good for resisting vertical and lateral loads.
Application target	• To strengthen buildings with inadequate amount of shear walls on both sides. • To strengthen the walls with inadequate thickness and reinforcement. • To increase lateral stiffness. • To solve soft storey/ weak storey problem. • To solve staggered column building problems.
Application areas	• Beams and Walls.
Demerits	• The additional weight to the structure and that it requires a lot of work.

	• It may lead to building that uses disturbance during the time application. • It will require additional construction of foundations.
Strengthening options	Steel Bracing
Characteristics	• It yields better results in flexible frame. • It gives minimal building use disturbance to the users during construction time. • It is a viable alternative to the shear walls in a concrete framed building in seismic regions. • Its application barely causes a small mass increase with minimal cost. • It applies to the frames with inadequate lateral resistance. • It could be applied to the asymmetrical building since it will not add much weight to the structure. • It is suitable for plaza type buildings.
Application target	• Used for frames with weak short columns. • To increase frame stiffness by providing alternate stiff lateral load resisting system. • To control, overturning forces by applying, externally, onto the building.
Application areas	• Walls between columns and beams. • At weak storeys.
Demerits	• It has non-ductile failure pattern. • It could be liable to corrosion if not protected. • It might be difficult to construct.
Strengthening options	Fiber Reinforced Polymer
Characteristics	• It improves the ductility and energy absorption capacity of RC columns. • Its application delays the degradation of stiffness of the reinforced concrete columns. • It does not alter the dynamic response of the frame; rather, it changes the damage location and pattern in the frame. • It has high strength to weight ratio compared to other strengthening materials. • Aesthetic appeal, light weight and non-corrosive.
Application target	• To eliminate non-ductile failure mode. Example is shear failure. • To account for missing transverse reinforcement at joints. • It is used for flexural, axial confinement and shear upgrade and equally for crack control.
Application areas	• Columns • Beams, slabs, walls. • Wooden beam, column. • Masonry.
Demerits	• It has a high cost. • It has brittle behavior. • It is inadequate as fire resistant.

	• It does not possess the ductility that steels have. • Its brittleness could limit the ductile behavior of RC member strengthened by this method.

Table 3: Hybrid methods

Names of the methods	Characteristics	Application target	Application area
Steel Jacket/FRP Jacket	It is less expensive. It is aesthetically pleasing.	Improves bearing capacity.	Slabs with openings. Ribs slabs. Members with corroded internal reinforcement.
Shear wall/ Column Jacketing	It gives better performance to the individual method	Controls lateral stiffness and weak column.	Columns and between columns.
Shear wall/ steel beam.	It gives better performance compared to the separate methods.	Controls lateral stiffness and reduce longer span.	Between the columns and on beams.

2.1 Global strengthening strategy

This strategy involves an overall check on the performance of the whole building. The building might also be severely deficient under the design of the seismic forces. It takes control on lateral strength and stiffness of the building. Therefore, when the general performance of the building is selected as a target, this method should be considered [13, 14]. Examples to the strengthening methods under this strategy are the applications such as; steel bracing, shear wall and infill wall. With this strategy the issues solved are given as follows: Irregularities in the structural configuration and the increased forces on columns located at the corners of the building. The torsional irregularity is caused by the asymmetry of the building plan. Buildings with roof top and overhead water tanks could result with an asymmetry of the structure. Discontinuity of columns at ground floor. Curved buildings may result with an asymmetry of the building. Another factor is reduction in lateral strength from the top of the storey down to the ground floor.

2.2 Local strengthening strategy

In this method, strength and ductility of building members are targeted. They do not affect the lateral strength of a building or its total structural performance [13, 14]. Through the said means, the capacity of the members such as; the slab, beam and the column can be improved individually. The problem could be seen as a result of an improper design, as the poor construction and poor quality materials involved. Hence, there will be an individual failure of the building members either by shear or flexural failure of beams, columns and walls, beam-column joints, slab-beam or slab-column connections. Example of this method is; concrete jacketing, steel jacketing, steel plating and fiber reinforced polymer strengthening applications.

2.3 Integrated strengthening strategy

This involves the combination of different methods of strengthening in order to achieve the desired strength. This could be the hybrid of two local strategies to achieve a specified demand or an addition of a global strategy to a local strategy. Example is a combination of FRP wrap and steel bracing. It is effectively used to control joint shear failure, stiffness and also to reduce maximum inter-storey drift of frame structures [7]. Another hybrid is FRP and Steel Jacket that can be used for the structural members of some deteriorated reinforcement or corroded internal reinforcement [1].

Other integrated methods are; the shear wall and column jacketing, shear wall and steel beam, bracing and column jacketing, bracing and steel beam, and the steel beam and column jacketing. These hybrids, however, have given better results compared to the application of a single method of various options.

2.4 The Decision Selection Program

The decision selection program is a tool encoded with the properties of strengthening methods according to the seismic regions, strengthening strategies and its characteristics and building problems. Fig. 1 demonstrates the coded system for the decision program. The numbers in one (1) depict the property as highly applicable as found from the literature while the numbers in zeros (0) depict the property as not applicable. The left hand side (α) contains the applicable characteristics while the right hand side (β) indicates the values when problems are selected from the vertical column called "choice". These values are summed up and the greatest is produced in the relevance and the proposition counted, through the program, as the final decision. Although, Fig. 1 is embedded and could not be seen by the user of this program, Fig. 2 details the visible phase, where the selection of problems could be carried out. The relevance shows how much percentage a strengthening method is viable for solving problems encountered in such building under investigation. Its value is obtained through equation 1.

$$Relevance = SUM\ (\beta)/\ SUM(choice) \qquad (1)$$

Fig. 1 is the embedded part of the decision selection program. The building problem parameters considered are on the vertical left side of the program while the strengthening methods are arranged on the top horizontal part of the program. All the parameters considered are commonly found problems in older existing buildings, which require strengthening. Also the building irregularities to consider must be found from the building assessment. The building irregularities considered are but limited to the few as contained in the program. The choice on the left vertical column determines the number of times about the problems encountered in building selected and will be recorded in the strengthening methods required to solve them. The recording appears in (β) columns. The strengthening methods with the highest value are considered as the most efficient ones, according to the parameters contained in the decision selection program.

		α														β												
	Choice	Shear walls	Steel bracing	Concrete jacketing	FRP jacket	Steel plating	Steel jacketing	FRP wrap	FRP / steel bracing	FRP / steel jacket	span shortening	FRP strip	soil improvement	Shear wall/column														
Seismicity																												
Non seismic	0	0	1	1	1	1	1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Low seismic	1	1	1	1	0	0	1	1	0	0	0	0	0	0		1	1	1	0	0	1	1	0	0	0	0	0	0
Seismic	0	1	1	1	0	0	0	0	1	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Strengthening strategy																												
Global strategy	0	1	1	1	0	0	0	0	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0
Local stagtegy																												
Column																												
low dimensions	0	0	0	1	1	1	1	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0
degraded column	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
missing transverse rebars	0	0	0	1	1	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
low concrete grade	0	0	0	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
short column	1	0	1	0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0
strong beam/weak column	0	0	1	1	1	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0
corroded internal rebar	1	0	0	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	1	0	0	0	0
Joints																												
missing transverse rebars	0	0	0	0	0	0	0	1	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Beam																												
low concrete grade	0	0	0	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
low dimensions	1	0	0	1	1	0	1	0	0	0	0	0	0	0		0	0	1	1	0	1	0	0	0	0	0	0	0
missing transverse rebars	0	0	0	0	1	1	1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
over stressed beam	0	0	0	0	0	0	0	0	0	0	1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Slab																												
low thickness	0	0	0	1	0	0	0	0	0	0	0	1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
inadequate rebar	1	0	0	1	0	1	0	0	0	0	0	1	0	0		0	0	1	0	1	0	0	0	0	0	1	0	0
long span	0	0	0	0	0	0	0	0	0	0	1	1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Foundation																												
low dimensions	0	0	0	1	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
weak soil	0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Building irregularity																												
Regular	1	1	1	1	1	1	1	1	1	1	1	1	0	1		1	1	1	1	1	1	1	1	1	1	1	0	1
Irregular																												
Unsymmetric																												
projecting elements	0	0	1	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
open floor	0	1	1	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
floating/staggered column	1	1	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	0	0	0	0	0	0	0
plaza type building	0	0	1	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
mass irregularity	0	0	0	0	0	0	1	1	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
Summation	7	6	10	12	7	7	7	4	3	4	3	4	1	4		3	3	4	2	2	3	2	1	2	1	2	0	1
Relevance	1	0.4	0.4	0.6	0.3	0.3	0.4	0.3	0.1	0.3	0.1	0.3	0	0.1														

Figure 1. Encoded systems for the comparison of the strengthening methods

Seismicity	
Non seismic	No
Low seismic	Yes
Seismic	No
Strengthening strategy	
Global strategy	Yes
Local stagtegy	
Column	
low dimensions	No
degraded column	No
missing transverse rebars	No
low concrete grade	Yes
short column	No
strong beam/weak column	Yes
corroded internal rebar	No
Joints	
missing transverse rebars	Yes
Beam	
low concrete grade	Yes
low dimensions	No
missing transverse rebars	No
over stressed beam	Yes
Slab	
low thickness	Yes
inadequate rebar	No
long span	No
Foundation	
low dimensions	No
weak soil	No
Building irregularity	
Regular	Yes
Irregular	
Unsymmetric	
projecting elements	No
open floor	Yes
floating/staggered column	No
plaza type building	No
mass irregularity	Yes

Strengthening options	Shear walls	Steel bracing	Concrete jacketing	FRP jacket	Steel plating	Steel jacketing	FRP wrap	FRP / steel bracing	FRP / steel jacket	span shortening	FRP strip	soil improvement	Shear wall/ column
Relevance	0.43	0.43	0.57	0.29	0.29	0.43	0.29	0.14	0.29	0.14	0.29	0	0.14
Availability	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes
Building use disturbance	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No
Proposition	0	0.43	0	0.29	0	0	0.29	0	0	0	0.29	0	0.14
Strengthening Choices	Shear walls	Steel bracing	Concrete jacketing	FRP jacket	Steel plating	Steel jacketing	FRP wrap	FRP / steel bracing	FRP / steel jacket	span shortening	FRP strip	soil improvement	Shear wall/ column

Figure 2. Decision selection tool

3. CASE STUDY

The building is a four-storey, old and existing building with a basement floor as detailed in Fig. 3. It is a residential apartment and was designed and constructed in 1970 with no consideration of Earthquake Code's design. Fig. 4 gives the details of the frame with shear wall, while Fig. 5 reveals the details of the typical floor plan of a building.

The building investigated is located in Famagusta, Cyprus. It was modeled and assessed using STA4-CAD software, the analysis and seismic performance was carried out with the ACI 2005 code and Turkish 2007 Earthquake Code, respectively. Strengthening with shear wall was directly applied to this building without comparing with other methods, since it is a commonly applied technic in this region with very low material cost obtainable. However, the building problems will be used to run the decision selection tool. Therefore, the aim of the case study is to compare this notion with the decision selection tool recommendation, and to see if it will result with a suitable strengthening method with respect to the related building problems. This will serve as a testing criterion for checking the workability of the decision selection tool.

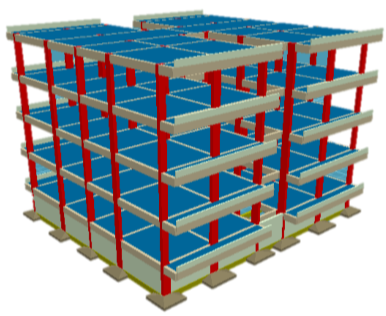

Figure 3. Four-storey frame structure

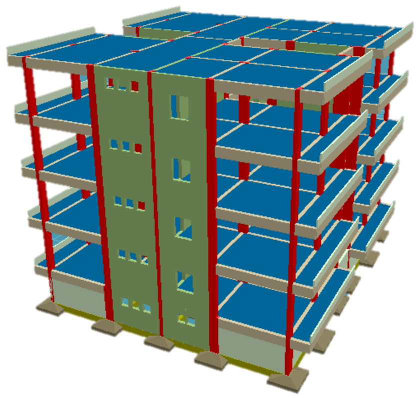

Figure 4. Frame with shear wall

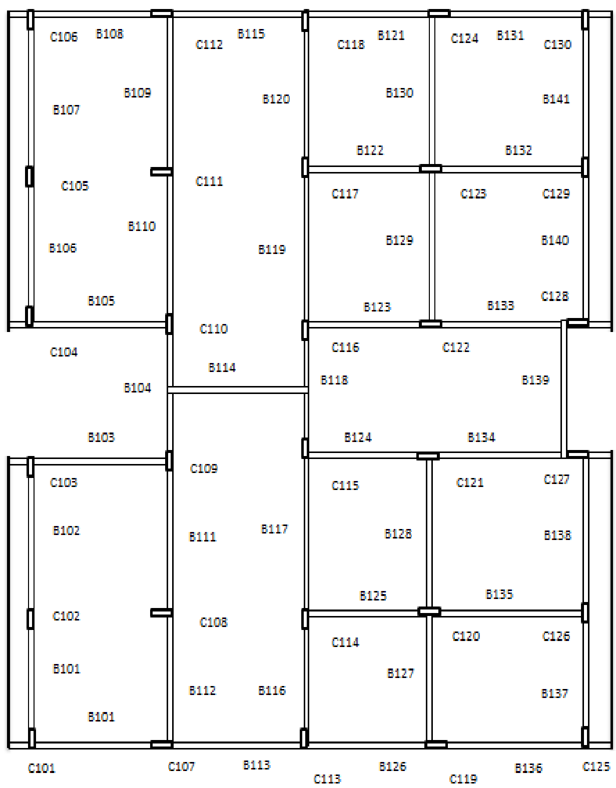

Figure 5. Typical floor plan

3.1 Building Information

Tables 4 and 5 detail the building information as contained in the building drawings, while Table 6 details the building earthquake parameters.

Table 4: General building information

Storey number	4
Storey height	$14.5\ m$
Concrete strength	$160\ kg/cm^2$
Steel grade	$2200\ kg/cm^2$
Slab thickness	$20\ cm$
Emodulus	$275323\ kg/cm^2$
Beams	20 cm by 50 cm
Column type-A	
Basement floor	20 cm by 60 cm
Floors 1, 2, 3 and 4	20 cm by 50 cm
Foundation size	195 cm by 195 cm
Column type-B	
Basement floor	20 cm by 50 cm
Floor 1, 2, 3, 4	20 cm by 40 cm
Foundation size	160 cm by 160 cm
Tie beam size	20 cm by 40 cm

Table 5: Reinforcement and stirrups

Name	Column A-type	Column B-type	Stirrup
Basement floor	6Ø18	6Ø16	Ø6/17
Floor 1	6Ø16	6Ø14	
Floor 2, 3 and 4	6Ø14	6Ø14	
Name	Beam		
Top bar	2Ø12		
Bottom bar	4Ø16		

Table 6: Building earthquake parameters

Building importance factor: I	1.0
T_A	0.15 s.
T_B	0.4 s.
Structural behavior factor: R	4
Seismic zone coefficient: A_0	0.3
Live load reduction factor: n	0.60
Assumed allowable soil pressure	$20\ t/m^2$

3.2 Building Assessment Result

Table 7 details the performance results of the building found from the building assessments. Assuming that the same properties of the building are maintained, no physical deterioration has been found from the initial site assessment, and also there is no change or modification in the structural design from what is contained in the structural plan and on the site.

Table 7: Performance results of the building

Beam damage ratio	86.4 %, (> 20%) TS2007
Column damage ratio	54.1%, (> 30%) TS2007
Building performance	Collapse case
Period	0.82 s
Joints connections	Low moment resistance
Frame stiffness	Low stiffness
Concrete strength	Low concrete grade

The general performance of the building is the collapse case with beam collapse prevention damage ratio of 86.4 % and column with plastic hinge V_c Ratio of 54.1 %. These were greater than 20 % and 30 % respectively for maximum damage limit for building standards of Turkish 2007 Earthquake Code utilized by STA4-CAD. Weak columns and beams, beams with low moment resistance at joints, and frame low stiffness were found due to the weak concrete grade. Therefore, the damage capacities were very high, and the general performance is at risk.

3.3 Evaluation with Strengthening Decision Selection Tool

The aim is to obtain the best strengthening method from the list of methods and parameters contained in the decision selection tool. The strengthening method recommended will be based on the problems found in this building. Table 8 (a) and (b) presents the evaluation for the investigated building.

Table 8 (a): Result of the evaluation of the case study

Seismicity	
Non seismic	No
Low seismic	No
Seismic	Yes
Strengthening strategy	
Global strategy	Yes
Local strategy	
Column	
Low dimensions	No
Degraded column	No
Missing transverse rebars	No
Low concrete grade	Yes
Short column	No
Strong beam/weak column	Yes
Corroded internal rebar	No
Joints	
Missing transverse rebars	No
Beam	

Low concrete grade	Yes
Low dimensions	No
Missing transverse rebars	No
Over stressed beam	No
Slab	
Low thickness	No
Inadequate rebar	No
Long span	No
Foundation	
Low dimensions	No
Weak soil	No

Table 8 (b): Result of the evaluation of the case study cited

Building irregularity													
Regular				Yes									
Irregular													
Unsymmetric													
Projecting elements				No									
Open floor				No									
Floating/staggered Column				No									
Plaza type building				No									
Mass irregularity				No									
Strengthening options	Shear walls	Steel bracing	Concrete jacketing	FRP jacket	Steel plating	Steel jacketing	FRP wrap	FRP / steel bracing	FRP / steel jacket	Span shortening	FRP strip	Soil improvement	Shear wall/ column jacketing
Relevance	0.5	0.67	0.3	0.33	0.2	0.3	0.2	0.5	0.5	0.2	0.2	0	0.3
Availability	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes
Building use disturbance	No	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No
Proposition	0.5	0	0.3	0.3	0	0	0.2	0	0	0	0.2	0	0.3
Strengthening Choices	Shear walls	Steel bracing	Concrete jacketing	FRP jacket	Steel plating	Steel jacketing	FRP wrap	FRP / steel bracing	FRP / steel jacket	Span shortening	FRP strip	Soil improvement	Shear wall/ column jacketing

4. RESULTS AND DISCUSSION

Table 8 (a & b) gives the details of the final result of the evaluation of the decision selection tool. During the relevance count, it can be seen that steel bracing strengthening method is best recommended while shear wall, FRP and steel jacketing and FRP and steel bracing as a hybrid method have the same values as the next alternative. However, by judging the material availability, building disturbance and application expertise, shear wall is selected as the best among other methods recommended in the relevance count. This is evident in the proposition count. However, steel bracing would have offered relatively high efficiency with respect to its value in the relevance count, but due to the proposition value which is good for the economy, it became shortlisted. This is same for the other hybrid methods with higher values in the relevance count, but lower in the proposition count. The proposition value is, however, affected by geographical region, where any building that requires strengthening is located. If the building is located in a region, where steel bracing materials is most available in that instance, it will be advisable to apply steel bracing. Therefore, the decision selection tool selected these methods as the best option according to the problem requirement of the building, as clearly seen in the relevance count. In the proposition count, the final decision for the selected method is rated, which is the shear wall. Fig. 9 is a bar graph detailing these values on each strengthening method as obtained from the decision selection tool.

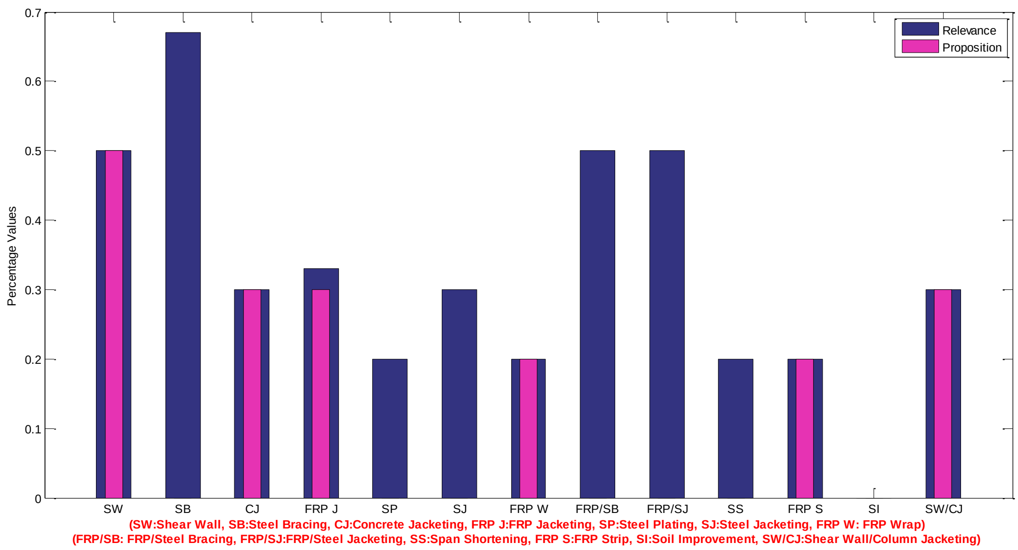

Figure 9. Relevance and proposition count in the case study

5. CONCLUSIONS

A tool for strengthening decision selection is presented. The tool is based on the advantages and disadvantages of strengthening methods with the strengthening application target. The problems which are readily found in building after assessment are encoded, with building irregularities and seismicity of the building region. It compares the problem found in the building with the strengthening options contained in the tool to recommend the best strengthening method to be utilized. It uses relevance for efficiency judgment and proposition for economic judgment.

In this study, it has been found out that the best strengthening method recommended by the tool is Steel bracing in the relevance count, followed by shear wall, FRP and steel bracing, FRP and steel jacketing as hybrid methods. But due to availability of materials and expertise, shear wall became the best recommended in the proposition value. However, this result has also shown that other strengthening methods such as the hybrid methods mentioned could be preferable against the shear wall, if the expertise and availability of material is readily obtainable. This could be pronounced clear if the building is located in such regions, where they are readily available.

However, the decision tool has proven to be fast, without time delay, to recommend the best suitable strengthening method for those buildings, for which the assessment result is at hand. It has also provided an avenue to test several other strengthening methods and especially hybrid strengthening methods for its efficiency on a building, with respect to the problems found. There may be limitations in the structural strengthening software to offer all the strengthening methods application and comparison on a building, at an instance.

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