COMPARISON OF STRUCTURAL CONTROL SYSTEMS USING MULTI-CRITERIAL ANALYSIS

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ABSTRACT:
This paper aims to achieve an optimum version of structural control systems using a multi-criteria analysis. In the beginning we accomplished a brief description of the structural systems proposed for the analysis, and then we described the properties of each system. For the multi-criteria analysis we used the global utility method. This analysis was made by choosing four common criteria for each proposed system; then scores were given for each criterion according to the importance considered by the researcher who performed the analysis. In the end, we achieved the structural control system which is optimum considering the proposed criteria and taking into account their shares.

1. INTRODUCTION
Every day the world’s major cities are facing smaller environment for new buildings and also a growing number of old buildings that need to be rehabilitated (Anastasiu, 2009).

The need to strengthen the buildings is influenced by the earthquakes which have affected much of the constructions and, hence, techniques and technologies have been developed and new concepts have emerged in the construction field.

2. MAIN BODY
One of the new concepts is the structural control systems, which has emerged as an alternative to the conventional design/consolidation. The purpose of using it is to reduce the negative effects of the seismic response (Renle et al., 2013).

Thus this concept defines the structure as a dynamic system in which the elastic, damping and inertia properties of the structure are adjusted in order to reduce the movements, speeds and accelerations given by the seismic answer (Renle et al., 2013).

The structural concept can be achieved by introducing in the structure: seismic isolators which reduce the energy induced by earthquakes; dampers through which the great part of the energy induced by the earthquakes is dissipated; additional mass which attenuate the vibrations of structure; actuators which generate control forces (Renle et al., 2013).

The structural control can be divided in four categories: passive, active, semi-active and hybrid.

2.1 Description of the structural control systems

2.1.1 Active control systems
The active control systems are widespread in Japan. They are used in high structures of over 300 meters, with a much improved dissipative and damping capacity for effectively balancing the seismic oscillations induced in a structure (Branco and Guerreiro, 2011).
They are based on a system of actuators that apply the forces of the structure that are controlled in real time to reduce the seismic response of the structure (Renle et al., 2013).

The active control systems have the following components (Renle et al., 2013):

1. Sensors: they have a double role, namely to measure real-time kinematic parameters of the earthquake (displacements, velocities, accelerations) and to measure the response of the structure to the seismic action.

2. Controller: this is the control device which processes the information transmitted by the sensors. It is based on a predetermined control algorithm that compares the received signals with the desired response, it calculates the necessary control forces and emits signals to activate the actuators.

3. Actuators: they are generally hydraulic and are the ones which generate the control forces acting on the structure. They are supplied by external energy forces.

2.1.2 Semi-active control systems

The semi-active control systems have the same mechanical properties as the passive control systems, only that they are adjusted via a control device powered by a battery (Zaharia, 2004).

The semi-active control system uses devices which need a small power supply necessary only to adjust its properties and to develop control forces opposing to the structural movement (Renle et al., 2013).

As an operating mode, the semi-active control systems are similar to the active ones, where the signals sent by the sensor are processed by a controller (based on a predetermined control algorithm) which emits signals for activating the actuators. The difference is that the actuators (powered by a small non-interference power source) will act on the passive device to adjust its features and not on the structure. They can run on batteries/accumulators and are operational even when the supply from the electrical network is interrupted, thus the energetical autonomy is an important advantage (Renle et al., 2013).

2.1.3 Passive control systems

Passive control is achieved by introducing some devices in the structure, devices that don’t require power to become operational, which is why they are called passive devices. The goal is to decrease the inertia forces induced in the building by the earthquake. This occurs either by increasing the damping force, or by increasing the vibration period of the system. These devices are activated because of the movement produced by the earthquake (Zaharia, 2004).

Features of the structural control systems:

<table>
<thead>
<tr>
<th>Type</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active control systems</td>
<td>- Their efficiency for a wide range of frequencies of the disruptive action;</td>
</tr>
<tr>
<td></td>
<td>- They allow the real-time control of the seismic response, due to the stiffness and damping features of the structure;</td>
</tr>
<tr>
<td></td>
<td>- They have high costs for implementation and operating;</td>
</tr>
<tr>
<td></td>
<td>- They need extremely big external power source;</td>
</tr>
<tr>
<td></td>
<td>- They need a generator, which increases the costs;</td>
</tr>
</tbody>
</table>
2.2 The multi-criteria analysis of the structural control systems

In order to choose one of the structural control systems shown above, one can use the multi-criteria analysis.

In order to perform this multi-criteria analysis, we have chosen the three structural control systems previously presented, which may be used for the rehabilitation of a building.

The following criteria will be used for the multi-criterial analysis:
- the cost;
- the execution technology;
- the performing mode;
- the maintenance.

Each criterion taken into consideration will be given a score between 0 and 100 points, which will be rated according to the following table:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>25</td>
</tr>
<tr>
<td>Execution</td>
<td>25</td>
</tr>
<tr>
<td>Performance</td>
<td>25</td>
</tr>
<tr>
<td>Maintenance</td>
<td>25</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2. Direct estimated rates

We have scored each structural control system and, in the end, the optimum choice will be considered the one with the highest score based on these criteria.

Further we note each system as follows:
- Active Control Systems „S1”
- Semi-active Control Systems „S2”
- Passive Control Systems „S3”

The criteria will also be noted as follows:
- Cost „C₁”
- Execution „C₂”
- Performance „C₃”
- Maintenance „C₄”

Cost

We have chosen this criterion because it best reflects the investment effort, while giving the technical difficulties of each analyzed variant.

The question is to choose the option that has the lowest price but highest efficiency.

Each of these three systems will be given a score between 0 and 100 points for outlining their costs.

<table>
<thead>
<tr>
<th>Score</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>S₁</td>
</tr>
<tr>
<td>70</td>
<td>S₂</td>
</tr>
<tr>
<td>100</td>
<td>S₃</td>
</tr>
</tbody>
</table>

Table 3. Score for the cost criterion

The maximum score is for minimum costs and the minimum score is for maximum costs.

The Technology of Execution

This criterion is relevant for choosing the best solutions because it highlights the needed workforce, the difficulty degree for the installation of the structural control systems.

In the first option, the active control systems have a more complex technology which results in higher implementing costs, so the score for this criterion will be a small one, meaning 60 points. In the second option, the semi-active systems have a simpler implementation technology, so the score will increase at 80 points. In the last option, the passive systems have a simple technology of execution, so they will have a maximum score of 100 points.

<table>
<thead>
<tr>
<th>Score</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>S₁</td>
</tr>
<tr>
<td>80</td>
<td>S₂</td>
</tr>
<tr>
<td>100</td>
<td>S₃</td>
</tr>
</tbody>
</table>

Table 4. Score for the execution criterion

The Performing Mode

This criterion intends to identify the operational efficiency of these systems.

Therefore, the active systems show efficiency for a wide range of frequencies of the disruptive action and allow the control of the seismic response in real time, due to the adaptation of the rigidity and damping of the
structure. This is why the score is maximum, meaning 100 points.

The semi-active systems develop limited control forces compared to the forces developed by similar passive devices; therefore they will get 60 points.

The passive systems, due to their efficiency and better control forces than the semi-active ones will get a score of 90 points.

100 S 1
60 S 2
90 S 3

Table 5. Score for the performance criterion

Maintenance

This last criterion is very important because the maintenance and the reliability of the systems give them these qualities. However, there is the disadvantage that one of them requires electricity to function.

Thus, the easiest way to maintain is for the passive systems, which don’t need power source and this helps a convenient maintenance. Therefore, these systems will have a maximum score of 100 points.

The active systems need a more complex maintenance and electrical power and, consequently, they will have additional costs. Therefore the score will be 50 points.

As for the semi-active systems, they need a smaller power source and an easier maintenance, which gives them a score of 85 points.

50 S 1
85 S 2
100 S 3

Table 6. Score for maintenance criterion

The proposed analysed method is the global utility method, which is rather simple. The most representative criteria can be considered for comparison. In this paper the authors have presented only four criteria which they considered of importance, but the criteria can be modified according to needs.

The normalization or standardization involves the transformation of the criteria scores in comparable points, the measure units being smoothed by a function value or by a normalization procedure, their scores losing the size and corresponding measure unit (Agarofinet, 2010).

The normalization procedure of the performance matrix is performed by linear transformation and uses the following formula for the maximum feature (1) (Roman, 2012):

\[
\frac{a_{ij} - a_{j_{min}}}{a_{j_{max}} - a_{j_{min}}}
\]

where: \(a_{ij}\) – value of the indicator j associated to the project;
\(a_{j_{min}}\) – minimum value of the indicator j;
\(a_{j_{max}}\) – maximum value of the indicator j.

Following the normalization process of the matrix the following values are obtained according to table 7:

<table>
<thead>
<tr>
<th>Options</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>C3</td>
<td>1</td>
<td>0</td>
<td>0.75</td>
</tr>
<tr>
<td>C4</td>
<td>0</td>
<td>0.7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7. Matrix of normalized performance by linear transformation method

The normalization procedure of the performance matrix is performed by linear transformation and uses the following formula for the maximum feature (1) (Roman, 2012):

\[
\frac{a_{ij} - a_{j_{min}}}{a_{j_{max}} - a_{j_{min}}}
\]

where: \(a_{ij}\) – value of the indicator j associated to the project;
\(a_{j_{min}}\) – minimum value of the indicator j;
\(a_{j_{max}}\) – maximum value of the indicator j.

Following the normalization process of the matrix the following values are obtained according to table 7:

<table>
<thead>
<tr>
<th>Options</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0</td>
<td>0.4</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>C2</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>C3</td>
<td>1</td>
<td>0</td>
<td>0.75</td>
<td>25%</td>
</tr>
<tr>
<td>C4</td>
<td>0</td>
<td>0.7</td>
<td>1</td>
<td>25%</td>
</tr>
</tbody>
</table>

Final score 0.25 0.4 0.9375

Table 8. Matrix with final results

3. CONCLUSIONS

As it can be seen in Table 8, following the analyses performed, the system option with the maximum score is S3-Passive control systems. These systems gained the best score for three out of four proposed criteria.
It should be noted that the score is given by the person who performs the analysis, taking into account what he wants to achieve and what it is important to him.

4. REFERENCES


