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Application of Active Control System on the Seismic Response to Unreinforced Masonry Structure

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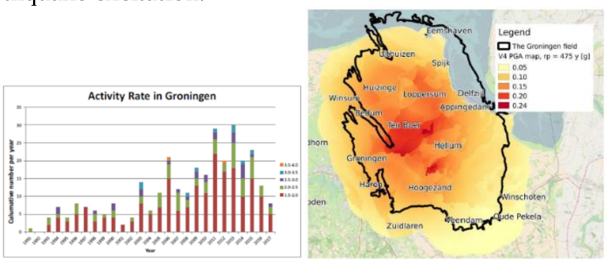
Abstract — **The increase of the human-induced seismicity in the Groningen has raised the awareness to ensure the structural safety and comfort for the affected residents. The current structural upgrading strategies mainly focus on improving the structural strength and stiffness of the load-bearing elements. Alternatively, active control could provide an additional dissipative energy mechanism by means of control forces. The effectiveness of the active control is assessed with multiple time history seismic events in the Groningen. Checking of the structural response with consideration of Significant Damage Limit State is conducted with a goal to prevent significant damage to the structure so that the cost of repair, demolishing, or even re-construction of new dwellings could be reduced. The preliminary calculation of the active control system dimension and the actuator capacity is conducted to see the practicability to provide a realizable control system.**

I. Introduction

The induced earthquake activities have been increasing due to gas extraction in the province of Groningen since the 1980s. The observed earthquake magnitude varies between M_L= 0.5 to 3.6 (Richter scale). Most of the buildings in the province consist of residential houses that were built in the 60s and 70s during the ‘baby boom’ period which increased the demand for dwelling places. The most common typology is traditional unreinforced masonry houses that consist of 2-3 stories. These buildings were built without any consideration of earthquake-proof design. Thus, these buildings are at risk of damage or even failure due to earthquake excitation.



(a) (b)

Fig.1.a Induced Earthquake Activities in Groningen [1]
Fig.1.b Probabilistic Seismic Hazard Map for Groningen for Period T=0.01 s (T_r= 475 years) [1]

The terraced house and semi-detached buildings are considered to be the most vulnerable typical buildings. They are particularly vulnerable in the direction parallel to both of front and rear façade due to relatively large openings, i.e. windows and doors. It results in considerably narrow piers to handle the lateral forces in the longitudinal direction where the structural system could be seen as a portal frame system since there are only narrow piers contribute to the structural stiffness, while in the transversal direction the lateral stability is provided by the in-plane wall mechanism from the solid wall. The terraced house becomes one priority in re-strengthening practice due to its vulnerability and the large distribution of the terraced houses based on the GIS database which contains information of about 275.000 buildings[2]. This report discusses the effectiveness and feasibility of the active control system application on a typical terraced house to solve the structural deficiency against induced earthquake excitation.

II. Modeling

A. Earthquake Excitations

Three major earthquake recordings are chosen with the consideration of the Richter magnitude scale, maximum peak ground acceleration, the significant duration, and different recording stations. The scaled-up 2012 event is added to verify the limit state of the Significant Damage.

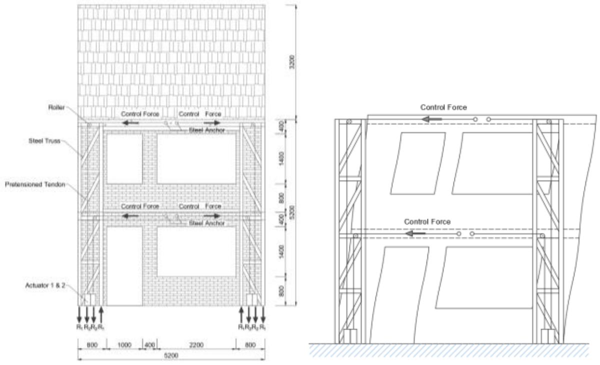
Table 1. Earthquake Excitations

Event	Location	M_L	Max PGA	Significant Duration
2012	Huizinge	3.6	0.017 g	26.01 s
2015	Hellum	3.1	0.017 g	3.35 s
2018	Zeerijp	3.4	0.115 g	3.32 s
Scaled up 2012	Huizinge	-	0.240 g	26.01 s

B. Active Control System Configuration and Modeling

Active tendon system is applied upon consideration that this type of actuator is generally lightweight, easy to install, required small space and able to reduce response for several excitation frequencies. The active tendon is not configured diagonally as it would obstruct the window and the door that could limit the accessibility of the house. Instead, the active tendons are attached vertically from the ground and then translated into the horizontal direction at every floor level by using additional steel trusses.

The ratio of opening and the façade area value adapts the average ratio of the terraced houses in the Groningen area which is 0.65[2]. The material properties of this project follow the result of previous real scale experiments conducted at TU Delft [3][4][5]. The façade wall is modeled with a 2D finite element model. The finite element analysis uses constant shear element (4 nodes with 2 degrees of freedom at each node) as the rectangular element is too stiff to produce the constant moment without also producing simultaneous shear stresses.



(a) (b)

Fig.2. (a) Active Control Configuration (b) Deformed Shape Scheme

The control scheme considers the predicted dominant global modes of the terraced house that contribute up to 90% of the modal mass participation ratio which mainly consists of horizontal deformation. The control force direction is set to be horizontal on each floor.

III. Results

A. Interstory Drift

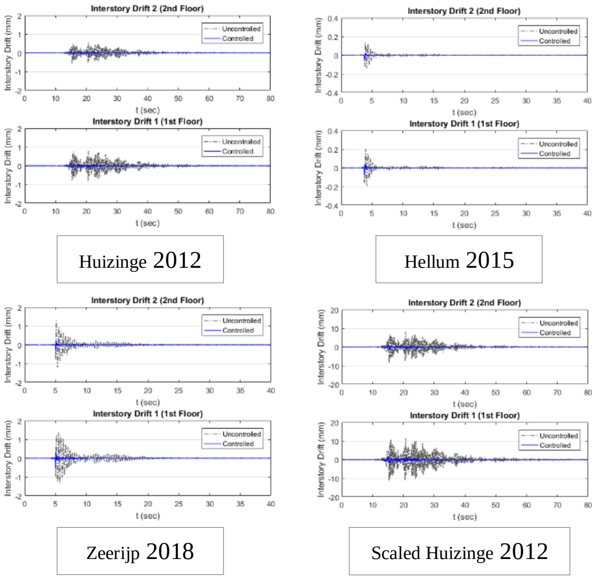


Fig.3. Cont. and Uncont. Interstory Drift for Various Seismic Events

The active control application by using LQR algorithm could reduce the structural response with peak inter-story drift reduction percentage of around 62%-87% and root mean square inter-story drift reduction of around 85-89% for various seismic excitation cases. The controlled inter-story drifts are always lower than the maximum inter-story drift limitation for unreinforced masonry structures of 0.004h as stated in EN1998:3 Assessment and Retrofitting of Buildings[6]. The maximum control force needed is governed by the Scaled Huizinge 2012 event with a value of 32.88 kN.

B. Stress Checking

The stress checking was conducted for both controlled and uncontrolled cases during excitation at critical points observed. In the controlled case, the tensile stress does not reach the in-plane masonry flexural strength perpendicular to the bed joint. Thus, no cracking is observed in the controlled case but with a close stress margin of 0.4 MPa.

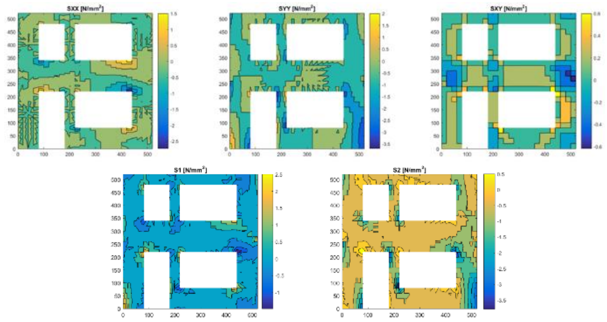


Fig.4. SXX, SYY, SXY, S1 and S2 Stress Contour Plots for Scaled 2012 Huizinge Event at t=15.73 s

The shear failure checking trough modified characteristic masonry shear strength formula[7] shows that the shear failure mode will not happen as the shear stress is always below the shear strength value.

No crushing/compression failure happens for both cases. The SXX and SYY do not reach the compressive strength parallel and perpendicular to the bed joints.

IV. Conclusion

The active control application could reduce the inter-story drift and stress effectively for various seismic excitation cases from moderate to strong earthquake motion. Results show that tensile failure (cracks) will not happen with a small stress margin before the tensile strength is reached. The shear failure mode of the unreinforced masonry could be prevented in the controlled case as well.

A small-scale active control system is realizable to be applied to typical terraced houses. Based on preliminary dimension calculation, at least a gap of 35 cm needs to be allocated between the inner and outer leaves of the cavity wall to accommodate the steel trusses and actuators. The active tendon needs to be connected to the concrete floor by attaching a steel anchor-active tendon connection. The foundation beam needs to be re-strengthened as there is an increase of the shear force from the support reactions. Additional foundation beam and shallow foundation might also be needed to support the shifted outer (red brick) leave.

Acknowledgment

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References

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