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Research Article

SEISMIC PERFORMANCE OF CLADDING SYSTEMS: EXPERIMENTAL WORK*

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Abstract

Cladding accounts for up to 25% of the cost of a building, has a major impact on its integrity, service life and preserves its appearance. In this paper the dynamic behavior of cladding systems of two projects in practice was investigated. The first project is the Great mosque project in Algeria and the second project is a high rise building in Almaty- Kazakhstan. In the first project stone cladding system was used and in the second project glass aluminum panel cladding system was used. Shake table tests were performed to verify the adequacy of the cladding system connection details. Test results shows that the designed façade detailing was appropriate and permit free movement of the curtain wall from the building structure without getting failures. The paper presents test specimens details, test results and the recommendation that the architect or the design engineer should take into consideration in designing cladding system connection details.

Keywords: Earthquake, glass aluminum panel cladding, shake table, stone cladding.

Araştırma Makalesi

BİNA KAPLAMA SİSTEMLERININ SİSMİK PERFORMANSI: DENEYSEL ÇALIŞMA

Öz

Modern binalar genellikle doğal taş veya cam alüminyum panellerin kaplama sistemlerine sahiptirler. Kaplama, bir binanın maliyetinin% 25'ini oluşturur, bütünlüğü ve hizmet ömrü üzerinde büyük bir etkiye sahiptir ve görünümünü korur. Bu makalede, iki büyük uygulama projenin kaplama sistemlerinin dinamik davranışı araştırılmıştır. İlk proje Cezayir'deki Ulu cami projesidir ve ikinci proje Almatı-Kazakistan'da bir kule projesidir. İlk projede taş kaplama sistemi, ikinci projede cam alüminyum panel kaplama sistemi kullanılmıştır. Bu çalışmada kaplama sistemi bağlantı detaylarının yeterliliğini doğrulamak için sarsma tablası testleri yapılmıştır. Test sonuçları, tasarlanan cephe detaylandırmasının uygun olduğunu göstermektedir ve kaplama duvarı hasar görmeden bina yapısından serbestçe hareket eder. Bu makalede test örnekleri detayları, test sonuçları ve mimar veya tasarım mühendisinin kaplama sistemi bağlantı detaylarının tasarımında dikkate alması gereken tavsiyeler sunulmaktadır.

Anahtar kelimeler: Cam alüminyum panel kaplaması, Deprem, sarsma masası, taş kaplama.

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1.INTRODUCTION

Buildings are often clad with architectural precast concrete, natural stone or glass aluminum panels that hang from the structure. Today, granite of 2.5 to 3 cm thick, or even thinner panels are used as exterior cladding on high rise buildings around the world. The cladding experts spend most of their efforts to determine the optimum thickness by checking mid-span thicknesses against design wind loads. They compare design flexural stress with test results from small samples of the actual material to be used in order to verify a safety factor of 3.0 (Larkin, 1998). The thickness is increased to prevent aging, loss of strength caused by exposure and the effects of weathering in some cases. Claddings are regarded as a deadweight that does not contribute any structural function to the building. Consequently, structural engineers often leave the choice of cladding and its connections entirely to the architect and precast concrete contractor. Conventional connection designs try to cancel the interaction between cladding and supporting structure due to seismic-induced inter-storey drift by isolating the panel from the main structure. Sliding or flexible connections are recommended to allow movement in the plane of the cladding panel, in this way lessening panel interaction with the supporting frame. Recent studies by (Paul PINELLI et al 1996) indicates that if the connections are engineered design the cladding system (particularly heavy precast systems) can provide increased stiffness, damping, and ductility to structures subjected to wind and earthquakes. The performance of Stone cladding and the Stone curtain wall is affected by the fixing element of Stone to the back structure or frame. Fixings should be installed easily and they should maintenance free. The materials used in the UK are various grades of stainless steel, copper and copper alloys. British Standards do not recommend the use of any other metals or alloys. In Turkey, most of the time because of economic reasons, some fixings are stainless steel and some are galvanized. If the fixing is open to the exterior climatic conditions and it is not in direct contact with stone but exposed to weather, it should be stainless steel, galvanized steel, zinc-rich painted or epoxy-coated steel, or aluminum. Corrosion of the fixing element decreases its strength. Earthquake loadings create stresses upon stone panels and fixing elements. Common cladding failures are due to poor location of panels during fixing and location of fixing holes. The thickness of stone panels affects this performance (Richardson;2001). Vandenberg (1975) emphasizes that complex junction details are used to allow movement between sections, but all elements should work together. In this paper the results of seismic performance test on natural stone and glass aluminum panel cladding connections are presented.

2.STONE CLADDING TESTS

The natural stone claddings were produced in Turkey and used for the Great mosque project in Algeria [9, 10]. The stone cladding system in this project is a rigid cladding system, it which it's natural period less than 0.06 sec. To obtain the design seismic force that effect on the cladding element most international codes provide simplified methods which depend on the response of supporting building, size and weight of the element, relative location of the element in the building, flexibility of the component, etc. In this project cladding connection, anchors, and stone unit size were designed to carry in plan (i.e earthquake forces) and out of plan forces using the Euro code 8. According to Euro code 8 simplified formulas the maximum acceleration response of the cladding was 2.5 time the ground acceleration. Shake table seismic performance tests were conducted to verify the designed connection details. The details of the test specimen are shown in Fig1. The steel structure which supports the cladding was designed to be very rigid and behave linearly during seismic excitations. Three test specimens were tested. The first specimen was subjected to earthquake excitations in the in plane direction (x direction) only. The base acceleration amplitude was increased up to 1.6 g and maximum acceleration response of the cladding and the supporting structure were measured and presented in Fig 2. At 0.5 g maximum base acceleration, cladding maximum response was about 1.26 g and Stone erosion at the contact with the support was observed as shown in Fig 13 a. At 0.75 g to 1 g maximum base accelerations the cladding response was approximately constant with maximum acceleration of 2.4 g and support lifting were observed as shown in Fig13 b. At 1.5 g the response drop due to a loose nut as shown in Fig 13c. The second specimen was subjected to the earthquake excitation in the out of plane direction only (y direction). The cladding performance was good and no damage occurs. The third specimen was subjected to earthquake excitations in three directions (x, y, and z). Test results indicate the importance of including vertical acceleration in the design parameters. Inclination of supports and shearing of the inking pin was observed as shown in Fig 13d. Test results indicate that the cladding system designed according to the Euro code is very conservative and it can resist about two times higher accelerations than design accelerations without sever damage.

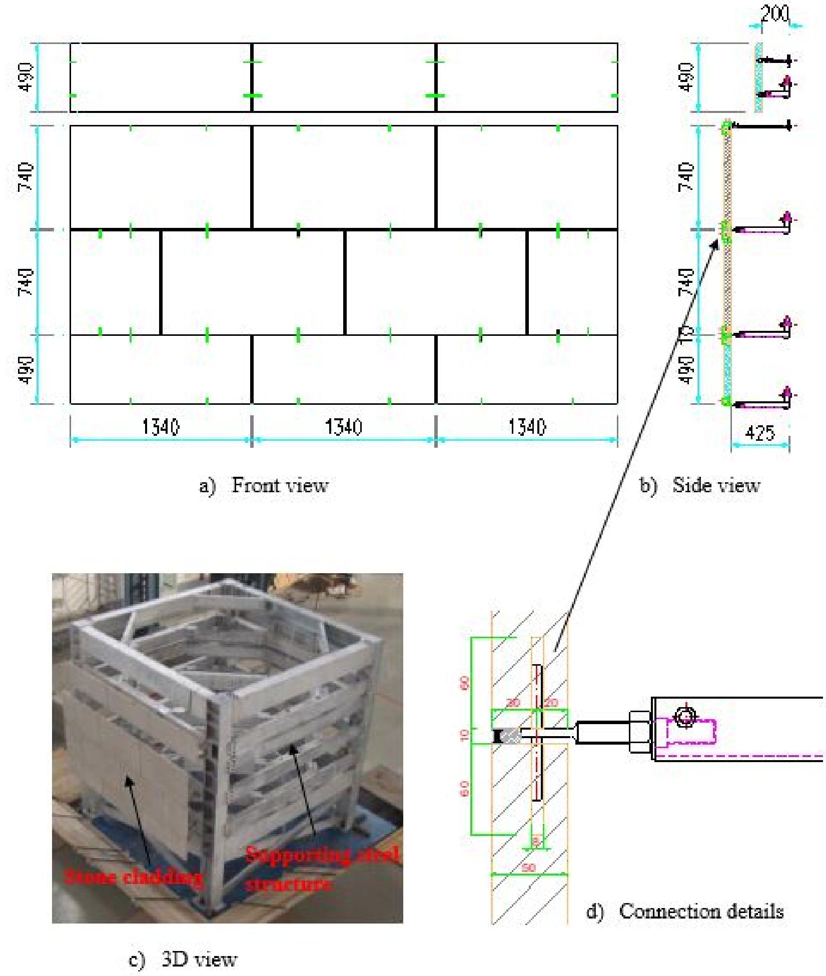


Fig 1. Stone cladding test specimen details

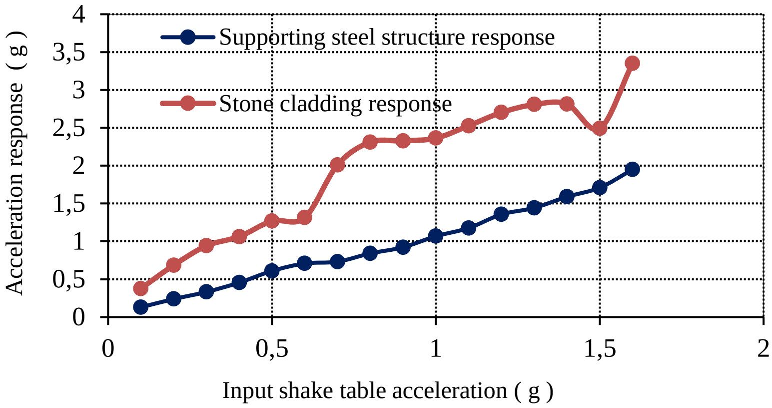
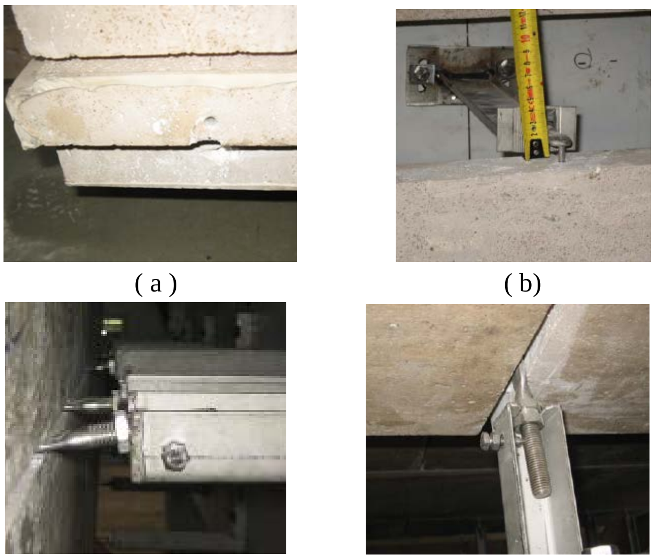


Fig 2. Test results



(a) (b)

(c) (d)

Fig 3. Failure pattern

3. GLASS ALUMINUM PANEL CLADDING TESTS

Several high rise building projects use aluminum glass panels for its cladding system. This research presents the results of seismic performance tests on the glass cladding system that used on at Tower building in Almaty- Kazakhstan. The planned cladding system involves 4.00 x 1.50 m double glazed glass panels encased in an aluminum frame. The height of the panels spans the entire story height. The panels are attached to the building by two U-shaped hooks at the top and are free to move at the bottom. This mounting system allows the panel to rock and rotate in the vertical plane without causing any stress. The horizontal and out-of-plane motions of the panels are restricted by channel-shaped guides with end plates attached to the top and the bottom floor slabs. Test carried out according to the testing procedure recommended in the AAMA Standard. The procedure is generally known as “Crescendo Tests” and involves subjecting the specimen to dynamic displacements composed of concatenated sinusoids at different frequencies. Each sinusoid involves rump-up and constant-amplitude segments. The input displacement time history that will be used in the tests is composed of two concatenated sinusoids, the first with a frequency of 0.8 Hz for amplitudes up to 75 mm, and the second with a frequency of 0.4 Hz for amplitudes above 75mm. The tests are run until one of the following occurs: glass fallout, inter-story drift exceeds 10%, and inter-story exceeds 150 mm. The performance criterion was set as 40mm, which is the allowable inter-story drift limit specified in seismic design codes for multi-story buildings. Test specimen and test step up are shown in Fig 3. From the test it was observed that the main factors that affect rocking motion of the panel to satisfy the AAMA standard is the top and bottom connections of the panel with the beam elements. It was observed that a Gap of 15 mm in the bottom connection is required to make the panel rack otherwise the panel may not rack and a damage may occur in the panel. To prevent the out of plan motion of the Panel the design engineer should use some L shape profiles at the bottom connection. The AAMA design standard investigates the behavior of the Panels under low frequency only; in future research the performance of the panels under high frequency should be investigated to take into account the effects of higher modes and the design standard may need to be modified.

4. CONCLUSIONS

Shake table tests on stone cladding indicate that cladding system designed using simple formulas provided in existing code can resist about two times higher accelerations than design accelerations without sever damage. This means that formals in the codes are very conservative. Cladding systems works as a tuned mass damper. Hence design code formulation may be modified to include this benefit effects. The failure pattern was mainly due to stone erosion at the contact with the support, a support lifting and loose nut. Stone erosion may reduce by warping very thin rubber layer around the steel bar that inserted in stone hole. From the test it was observed that the main factors that affect rocking motion of the panel to satisfy the AAMA standard is the top and bottom connections of the panel with the beam elements. It was observed that a Gap of 15 mm in the bottom connection is required to make the panel rack otherwise the panel may not rack and a damage may occur in the panel. To prevent the out of plan motion of the Panel the design engineer should use some L shape profiles at the bottom connection. The AAMA design standard investigates the behavior of the Panels under low frequency only; in future research the performance of the panels under high frequency should be investigated and the design standard may need to be modified. Based on the specified input displacements and the performance criteria, all specimens have successfully passed the tests.

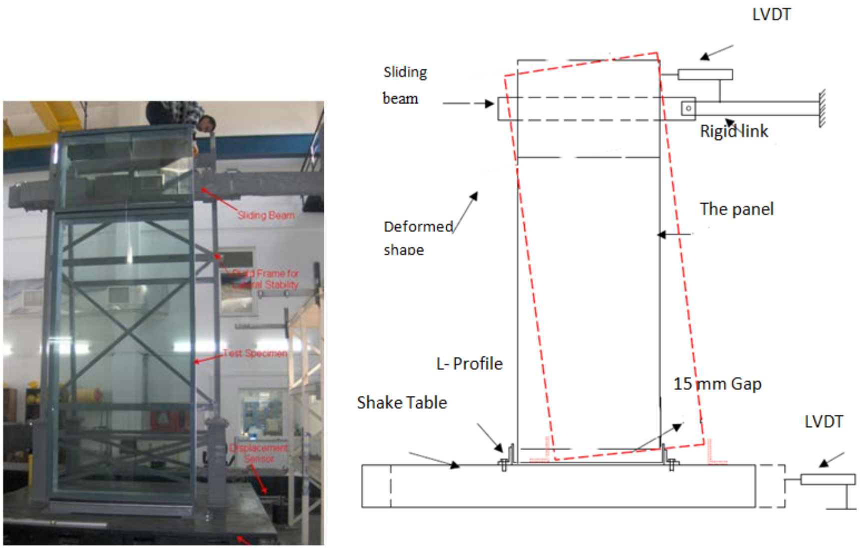
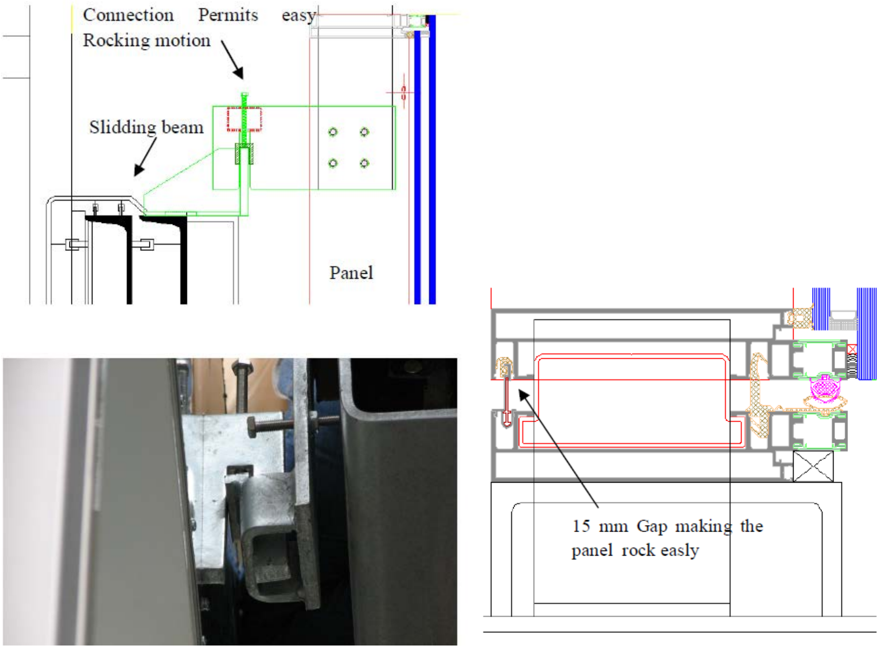
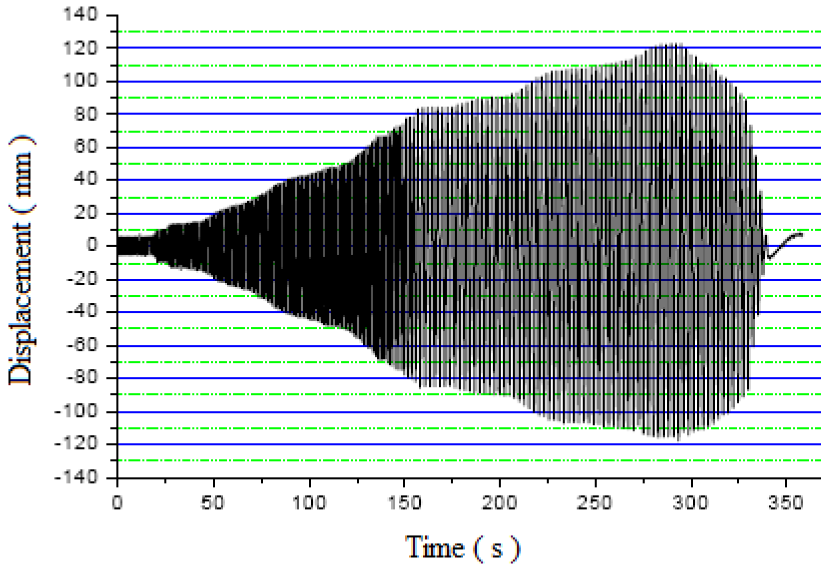


Fig 4. Aluminum glass panel test

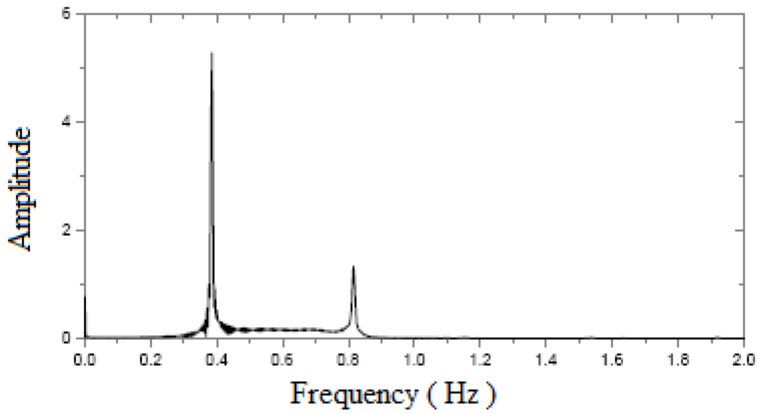


a) Top connection b) Bottom connection

Fig 5. Panel-structure connection details



a) Two concatenated sinusoidal displacements at0.8 and 0.4 Hz



b) FFT of the displacement time history

Fig 6. Shake table input displacement time history

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