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SEISMIC TEST PROGRAM OF SPECIAL DESIGNED CLAY BLOCKS DUE TO EARTHQUAKE RESISTANCE BY WIENERBERGER CONSISTING REAL SCALE SHAKING TABLE-, CYCLIC SHEAR-, DIAGONAL TENSION- AND COMPRESSION TESTS

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ABSTRACT :

WIENERBERGER has invented a special shape of modern, vertical perforated burned clay blocks for unreinforced masonry URM and confined masonry, which are optimized due to earthquake excitations without neglecting the today's needed demands in thermal insulation properties hereinafter called "WIENERBERGER POROTHERM–S blocks".
Therefore a project was started to identify and proof the effectiveness of structures and wallets constructed of these WIENERBERGER POROTHERM–S blocks.
This project includes the following test program:
a) Real scale shaking table test
A real scale structure constructed of WIENERBERGER POROTHERM–S blocks was tested due to artificial generated time histories in accordance to Eurocode 8 response spectrum and several real recorded earthquakes.
b) Cyclic shear tests
Cyclic shear tests have been performed with constant vertical loads and stepwise increased horizontal loads on real scale wallets. Next to the hysteresis (force-deformation plot), damping and ductility properties have been identified.
c) Diagonal Tension (Compression) tests
Diagonal compression tests have been done to identify the tension strength and furthermore the shear strength in order to compare these values with results of tests conducted with modern ordinary high perforated blocks.
d) Compression tests on blocks and mortar
To round up the parameters, compression tests on single blocks and mortar samples are performed according to actual European standards in order to evaluate the basic input parameters of the structural elements.

As a conclusion of all these tests, it was verified, that structures built with POROTHERM–S blocks are of extreme safety and have very high energy dissipation capacity, where high behavior and response factors can be considered, if response spectra analysis method is applied.

KEYWORDS: unreinforced masonry, confined masonry, clay blocks, shaking table tests, cyclic shear tests, behaviour factor, response value,

1. INTRODUCTION

Burned clay brick masonry constructions are one of the oldest construction methods which date back to 4000 BC in Mesopotamia. Most of historical buildings erected with burned clay bricks still exist. To point out only a few reasons for the success of clay masonry and why they are still used, aspects like durability, stable in value and good mechanical behaviour as a massive construction method are to be named.
WIENERBERGER was founded in 1819 in Vienna, Austria, and became the largest manufactory of bricks already in 1867 the world at the EXPO of Paris. Today WIENERBERGER is still the largest clay block

producer worldwide with 260 plants distributed on three continents (America, Asia and Europe) with its headquarter based in Vienna, Austria. WIENERBERGER was and still is is one of the leading companies in innovation and development of new clay blocks and other structural components made of burned clay. WIENERBERGER is meeting and the required demands and has the approach to be one step forward in order to keep its position as a trendsetter in this segment worldwide.

The blocks for building constructions produced today can not be compared with bricks in the past, although the main basic natural component, namely clay, remained unchanged. Burned clay blocks nowadays can be considered as high end products, which are optimised due to the needed demands. It is necessary to meet requirements due to mechanical stability, thermal and sound insulation and furthermore fire resistance. Modern standards and codes are becoming more and more challenging. Especially in higher seismic regions, where PGA for design reasons in codes are in the area of 0,30g or more, special designed clay blocks are necessary, still keeping and ensuring thermal insulation properties. In order to meet all requirements and to ensure safety due to earthquake excitations, a new block was invented and subsequently patented by Martin Kasa – the WIENERBERGER POROTHERM–S blocks.

It is obvious that energy dissipation during a seismic scenario in masonry walls can only be performed by appearing of cracks. This stage can also be called postelastic stage, which is related to plastic stage in eg. steel engineering. New special thinbed mortars for grinded blocks allow to create cracks in the mortar layer, but by using conventional mortar, which is also the case in earthquake prone areas, cracks will be distributed through bed- and head joints. Therefore the newly designed WIENERBERGER POROTHERM–S blocks should be able to capture a specific higher amount of mortar. On the other hand it is well known that mortar joints are heat bridges and therefore decrease the thermal insulation properties. The patented system of WIENERBERGER POROTHERM–S blocks has combined all these aspects, by also taking the reducing of thermal conductivity into consideration. Combining all the requirements, a consequent outcome due to research work is:
- special clay mixture in order to ensure a low thermal conductivity but high compressive strength;
- computer simulated and Finite Element Method analysed void patterns which increases the thermal insulation and also the horizontal block strength;
- special designed mortar pocket to decrease and optimise the thermal losses through the head joint;
- special designed additional mortar window, "seismic" mortar window.

Wienerberger
Building Value
POROTHERM

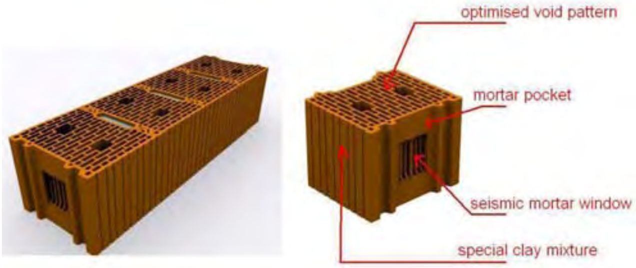

Figure 1 Shape of WIENERBERGER POROTHERM–S blocks

2. EXPERIMENTAL INVESTIGATIONS

2.1. Cyclic Shear Tests

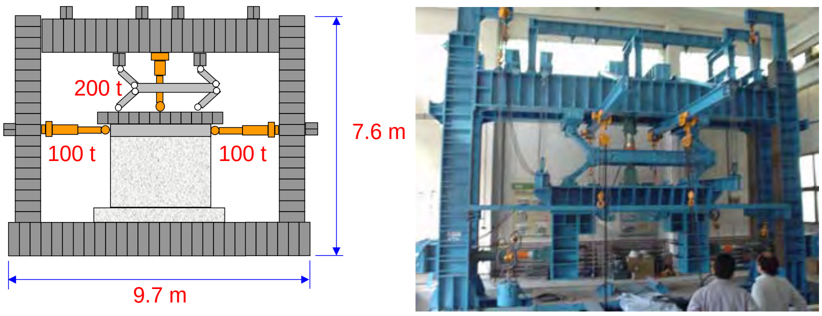

Figure 2 Reaction Frame

The cyclic shear tests were performed on a reaction frame. Loading begins with the application of vertical, axial normal force as a first step and is kept constant during the test. The axial force is applied with the vertical cylinder and is uniformly distributed by the rigid steel beam of the pantograph. Due to the pantograph, the rotation of the upper beam is constrained. In the second step, cyclic lateral force is applied under constant axial load. The cyclic load is controlled in displacements due to inelastic behaviour envisaged for tested specimens. After finishing cyclic loading the specimen is pushed up to failure in one direction.
Two wallets constructed with POROTHERM 30-S (l x h x t = 250 x 175 x 30 cm) have been tested until failure, where the vertical compression was kept at the level of 0.60 N/mm² in order to simulate the load of three upper storeys.

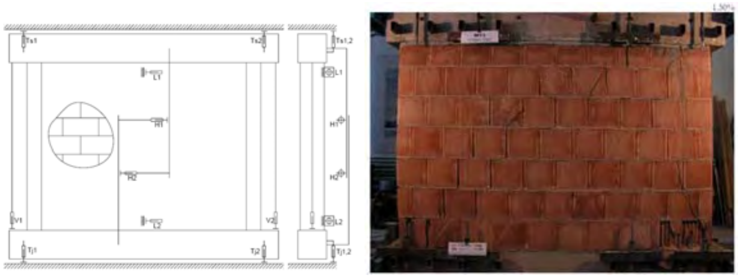

Figure 3 Instrumentation of LVTD´s

2.2. Diagonal Tension strength

Diagonal compressive tests have been performed on conventional blocks of same size and WIENERBERGER POROTHERM-S blocks in using the same mortar in order to evaluate the diagonal tensile strength of masonry, f_t.

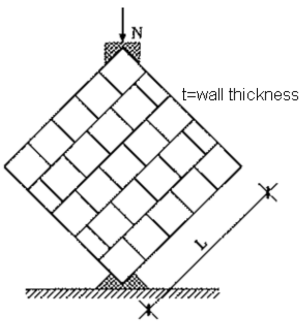

Figure 4 Diagonal tension strength

$$f_t = 0.45N / A \qquad (A=L \times t) \qquad (2.1)$$

Table 2.1 Results of diagonal tension strength

	conventional blocks [N/mm²]	**POROTHERM S-blocks [N/mm²]**
f_t	0.247	0.442
Difference		**+ 179 %**

2.3. Real Scale Shaking Table Tests

The testing programme has been selected on such a way that it provides the information for estimation of dynamic behaviour of the both masonry models subjected to simulated motion of selected earthquakes. The total mass of the tested model is 35.34t including additional mass of 10 t added at the top and mass of the foundation. The net mass of the model that is used for calculation of inertia forces is 28.34 t. Natural frequencies could be identified with sine sweeps and random tests at f_l= 7.57 Hz (translational) and f_2 = 14.7 Hz. (torsional).

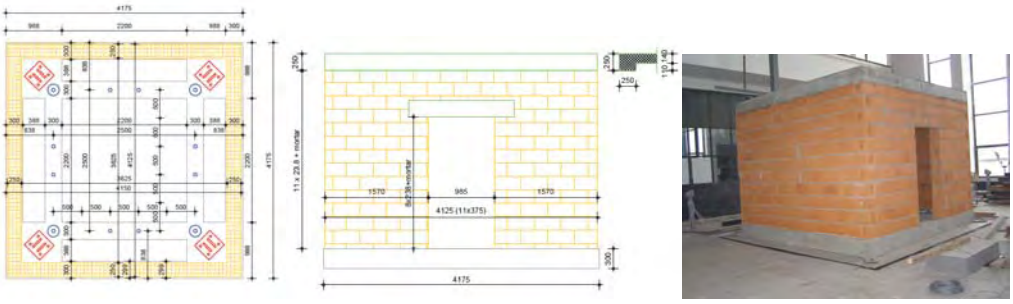

Figure 5 Diagonal tension strength

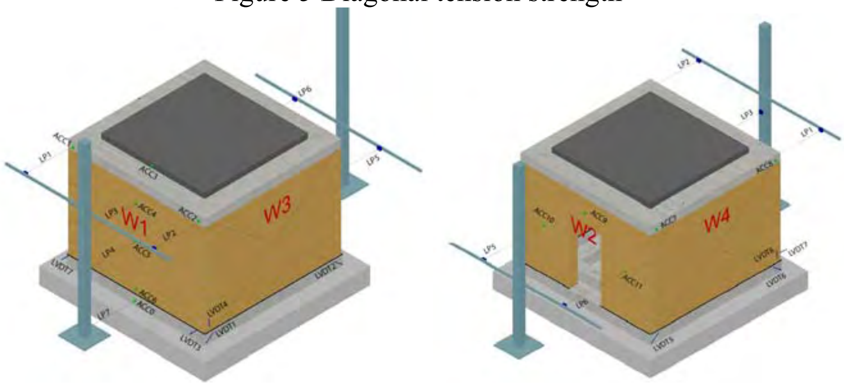

Figure 6 Indices and Instrumentation set up

Simulation of earthquake time histories have been done for three different artificial earthquakes generated according to the Eurocode 8 requirements in horizontal direction and also real recorded time histories from Imperial Valley, El Centro 1940 and Petrovac, Montenegro earthquake 1979. The artificial accelerograms were generated to match the Type 1 elastic response spectra for design ground acceleration ag = 0.30g on type B soil condition. All mentioned earthquake time histories were simulated in horizontal direction scaled to different intensitie-peak ground accelerations (PGA). The highest simulated input acceleration in horizontal direction, regarding the artificial earthquakes, is around 0.29g, while for real earthquakes the highest input acceleration was reached for simulation of scaled Petrovac earthquake. The highest input acceleration was 0.60g.
As a consequence of omitting bituminous strips to be thermally treated before layering on the foundation level, there was a forseen horizontal sliding of whole part of the first model (MODEL 01) above foundation during all earthquake tests. Therefore, a fixation construction was planned and applied to prevent this sliding, up to certain input levels of seismic action (MODEL 01R). Possible uplifting that exists in MODEL 01 due to rocking motion, was left unchanged. Testing programme have been extended with testing of MODEL 01R by repeating some tests performed for MODEL 01. MODEL 01R was then exposed to compressed (due to quake duration in time history) recorded real earthquakes up to the limit of the shaking table due to its pay load and simulated frequencies, to 0.76g.
There were no visible permanent damages, neither minor cracks in all walls after all performed tests with simulation of artificial earthquakes, in MODEL 01, nor increasing of initial cracks and developing of new ones in the MODEL 01R. There were visible cracks in all walls during and after performing all runs with simulation of compressed real earthquakes, where the aim of this compression was it to induce damages. In MODEL 01 beside the minor cracks in certain blocks of the walls, some larger cracks have been developed at the corners of wall W3 and W4, mainly due combined relative displacement (sliding) of the model in respect to the foundation and uplifting of the model due to rocking. In MODEL O1R in certain blocks new cracks have been developed, while the initial ones at the corners of walls W3 and W4 increased. But still, there were no major cracks that decreased the stability of the models after all performed shaking table tests by simulation of generated Eurocode 8 artificial earthquakes, as well as original and compressed real earthquakes (EL Centro and Petrovac) up to 0.76g!! In other words, the models withstand both, Eurocode 8 artificial as well as above mentioned real earthquakes in good condition. The results from final sine sweep and random tests showed that the first translational natural frequency dropped down, for MODEL 01 19%, and for MODEL 01R 8%.

2.4. Compression Tests

Additional to the previous mentioned tests, also single compressive tests on used mortar and blocks were evaluated according to EN 772-1.

3. INTERPRETATION OF RESULTS

3.1. Evaluation of Ductility of Shear Walls (structural member)

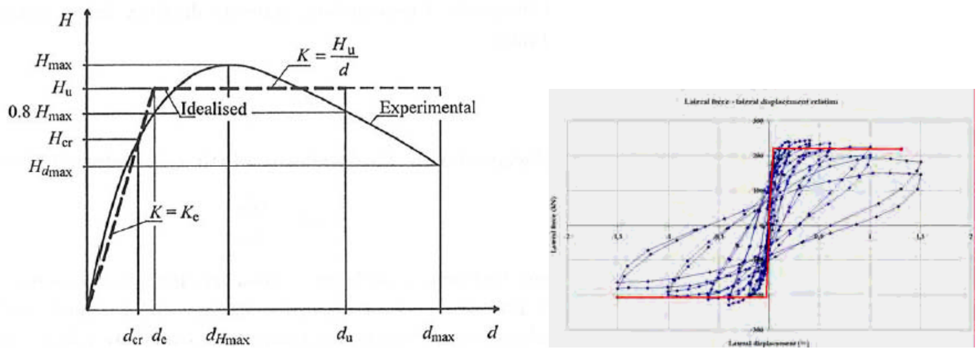

Figure 7 Bilinearization of the envelope of hysteresis

By taking a bilinear idealisation of the hysteresis envelope, H_u is evaluated by considering the equal energy dissipation capacity.
The idealised ultimate displacement d_u is defined as the displacement value, where the idealised line intersects the descending branch of the experimental one, but not more than at the value of 0.80 H_{max}, to ensure enough safety in ultimate limit design.

$$\mu_u = \frac{d_u}{d_e} \tag{3.1}$$

The displacement at the idealised elastic limit d_e is evaluated from

$$d_e = \frac{H_u}{K_e} \tag{3.2}$$

Following, the results of two real scale cyclic shear tests (wall size l x h x t = 250 x 175 x 30 cm) are presented and discussed due to the available ductility and furthermore behaviour factors.

Table 3.1 Results of cyclic shear tests

	Units	**Test 1**		**Test 2**	
Test Date		22.03.2007		17.05.2007	
Mortar: f_m	[N/mm²]	4.69		6.03	
Block: f_b	[N/mm²]	11.80		11.80	
Vert. compr.	[N/mm²]	0.60		0.60	
		POSITIVE	**NEGATIVE**	**POSITIVE**	**NEGATIVE**
d,max	[‰]	6.00	6.00	7.99	5.64
d,cr	[‰]	0.46	0.46	0.38	0.39
d,u (at 0.8 H,max)	[‰]	10.00	10.00	10.02	10.09
d,e	[‰]	0.62	0.64	0.58	0.45
μ,u	[ ]	16.19	15.52	17.14	22.53
μ,u$_{median}$	[ ]	**15.86**		**19.84**	

3.2. Evaluation of Ductility of Structures

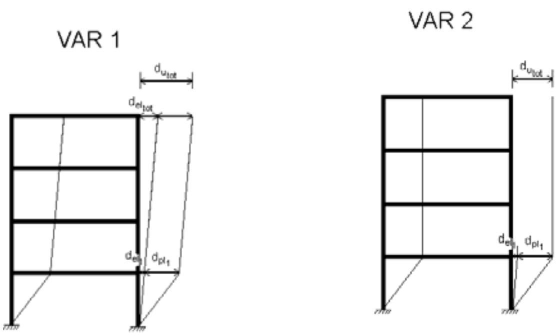

Figure 8 Structural ductility factors (left, VAR1); (right, VAR2)

Two boundary conditions are taken into consideration, where the ductility values of structures can be finally expressed as mean values of those two variants. In case of variant 1 (VAR 1), plastic and elastic deformations at the ground floor and furthermore elastic deformations in upper storeys are assumed. Structural ductility factor can therefore be expressed with Eqn. 3.3.

$$\mu_{structure} = \frac{d_u}{d_e} = \frac{\mu_{1stfloor} - 1}{k \cdot n} + 1 \tag{3.3}$$

Where n= storey number and k=1……n ≤ 2; k=2/3……n > 2

In case of variant 2 (VAR 2), plastic and elastic deformations at the ground floor are assumed where no deformations in upper storeys will be considered (as an extreme boundary case). The structural ductility can be limited to the member ductility and is expressed therefore in Eqn. 3.4.

$$\mu_{structure} = \mu_{1stfloor} \tag{3.4}$$

Table 3.2 Evaluation of ductility of cyclic shear tests

	Storey	**Test 1**	**Test 2**
μ,var 1	1	15.86	19.83
	2	8.43	10.42
	3	8.43	10.42
	4	6.57	8.06
	5	5.46	6.65
μ,var 2	n	15.86	19.83
μ,mean		**12.15**	**15.13**

3.3. Evaluation of behavior factors (q-value)

3.3.1 Pure q-values (q_0-value)

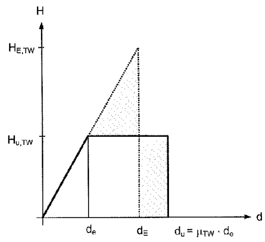

Figure 9 Structural behaviour factors

The behaviour factor can be analysed with the well established equation of assuming the theory of equal maximum, energy response.

$$q_{structure} = \sqrt{2 \cdot \mu_{structure} - 1} \qquad (3.5)$$

Table 3.3 Evaluation of pure behavior factors, q_0

	Test 1	**Test 2**
$q_{,structure} = q_0$	**4.83**	**5.41**

3.3.2 Overstrength value (OSR-value)

a) Overstrength of Structural Members: OSR 1
Overstrength of structural members is resulting from fractile values (characteristic strength, 95% fractile; 5% fractile) or from strength reserves in the material. In case of bilinearization of hysterisis envelope, ($H_u = 0.9 \cdot H_{\max}$) the member overstrength is defined with: OSR 1 = 1.10

b) Structural Overstrength: OSR 2
According to EN 1998-1 the structural overstrength is defined as: OSR 2 = α_u / α_1. OSR 2 is depending of the structural configuration. In common masonry structures, it could be found, that OSR2 can be defined with 1.40.

3.3.3 General behavior values (q-value)

The behaviour factors are evaluated with methods described above. These values are pure behaviour factors (q_0) without consideration of any overstrength. Taking overstrength values into account where, OSR 1 = 1.10 and OSR 2 = 1.40,

$$OSR_{,total} = OSR\ 1 \times OSR\ 2 = 1.10 \times 1.40 = 1.54. \qquad (3.6)$$

It can be seen, that q values given above are extremely on the conservative side. Beside safety factors given in codes for design, additional safety resulting from overstrength factor of OSR = 1.54. Expressing the overall behaviour factor (see Eqn. 3.7) for a statical response spectra analysis of WIENERBERGER POROTHERM S-blocks, out of two tests, table 3.4 gives an indication.

$$q = OSR_{,total} \times q_0 \qquad (3.7)$$

Table 3.4 overall behavior factors, q for POROTHERM S-blocks

	Test 1	**Test 2**
q	**7.44**	**8.33**

4. CONCLUSIO

Clay blocks with the specially designed and patent protected shape by Martin Kasa have been tested by several methods. From the results of all tests and investigations it can be seen that WIENERBERGER POROTHERM-S block represents an ideal solution for seismic prone areas. Even earthquakes up to 0.74g could be withstand by URM(!) without suffering from any major damages. Not only the safety is ensured by these blocks, but also other needed requirements like thermal insulation are met. Although modern special thinbed mortars for grinded blocks are also suitable and useable for higher seismic regions, WIENERBERGER POROTHERM-S blocks can be used with conventional mortar. After the experimental and analytical investigations, this product has been launched by WIENERBERGER in Croatia, Italy, Romania and Slovenia with a very high success.

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Earthquake, Masonry and Concrete Engineering Specialists

9 March 2017

To Whom it May Concern

I confirm that I have provided peer review for the Wienerberger POROTHERM Clay Construction System used for the Hibberd New Dwelling project at Weld Street Martinborough.

Confined masonry is a building system that is not widely used in New Zealand and for which we have no national design guidance. However, confined masonry is promoted in many other parts of the world in recognition of its proven satisfactory earthquake performance when designed appropriately. Most importantly, confined masonry is a codified construction technique in Europe, where its use is incorporated into Eurocode 8 "Design of structures for earthquake resistance" and Eurocode 6 "Design of masonry structures". In these Eurocodes there are no limitations placed on the level of seismicity that the confined masonry system can be designed to sustain.

I am a member of the standards committee for both NZS 1170.5 "Earthquake actions" and NZS 4230 "Design of reinforced concrete masonry structures". I am also a corresponding member for the masonry chapter of ASCE 41. I confirm that the loading applied in the design procedure for POROTHERM is consistent with the limit state loading criteria specified in NZS 1170.5. I also confirm that the design philosophy adopted for the design of POROTHERM is consistent with the philosophy of NZS 4230 in that the European approach to partial safety factors using a ratio of (1/1.5) is directly analogous to and mathematically consistent with the New Zealand approach of using a strength reduction factor of $\Phi = 0.75$.

The design of POROTHERM Clay Construction Blocks has been undertaken using two approaches. In the first approach an equivalent static design has been developed using the European factor q=2 which effectively corresponds within NZS 1170.5 to the ratio k_μ/S_p . The factor of q=2 recognises that confined masonry in effect has limited ductility, rather than being brittle. This value is codified into the Eurocodes and is well supported by technical literature and physical testing evidence. This methodology and the design shear strength for confined masonry have been used to establish that the in-plane response of the walls, appropriately accounting for torsion effects, exceed the design base shear demands.

The equivalent static analysis has been supplemented with a nonlinear pushover analysis using custom-written software developed in Europe specifically for the confined masonry system being used in this project. Within that software I confirm that all country-specific variables have been matched to the corresponding New Zealand-specific spectra. The design calculations provide further documentation to show that when subjected to design level earthquake loading the building loads and deformations are well below those corresponding to ultimate limit state strength and drift levels.

The out-of-plane analysis of the gable ended wall has been undertaken accounting for parts loading, consistent with the standard procedure adopted in New Zealand when assessing unreinforced masonry walls responding out-of-plane. The capacity of face loaded walls has been determined using the codified EN 1996-1-1:2005 + A1: 2012 Annex A procedure, and explanatory text has been provided to explain this procedure.

The detailing associated with the reinforced concrete boundary elements is consistent with Eurocode requirements for spacing of confining elements and the detailing of reinforcement within these confining elements, with supplementary strength checks for elements such as lintels having been undertaken using design software provided by the Structural Engineering Society of New Zealand.

The design of the floor and roof diaphragms are consistent with current New Zealand practice and are outside the scope of my peer review.

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