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Evaluation and Analysis of a Masonry Structure for Seismic Loading

Evaluation et calcul d'une structure en maçonnerie sous charge sismique

Untersuchung und Berechnung eines Mauerwerkbaus unter Erdbebenbelastung

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SUMMARY

Several steps must be taken to restore or rehabilitate an existing structure for various imposed load conditions. A history and condition survey of an existing structure revealed an inadequate resistance to seismic forces. Field testing and inspection revealed deficiencies in the original construction which required conformance to current Building Code. A structural analysis was carried out to determine the structural adequacy of the masonry walls and to facilitate rehabilitation in an economical way. This paper deals with the evaluation of existing clay tile block masonry work for retrofitting the structure.

RÉSUMÉ

Pour divers cas de charges, il faut effectuer plusieurs démarches afin d'assurer la réparation et la consolidation d'une structure existante. L'étude d'un ouvrage a montré une résistance parasismique inadéquate. Les vérifications sur le site ont mis en évidence les défaillances dans la construction initiale, la rendant non conforme aux exigences actuelles des normes. Les auteurs ont déterminé à l'aide d'un calcul statique la résistance du mur en maçonnerie, ainsi que les possibilités économiques du renforcement à envisager.

ZUSAMMENFASSUNG

Um ein Tragwerk gegenüber unterschiedlichen Belastungszuständen wieder auf eine genügende Tragfähigkeit zu bringen, müssen mehrere Schritte unternommen werden. Am Beispiel eines Tragwerks mit mangelhaftem Erdbebenwiderstand wurde zuerst die Vorgeschichte und der gegenwärtige Zustand aufgenommen. Untersuchungen und Inspektionen enthüllten Mängel in der ursprünglichen Konstruktion und der Erfüllung der heutigen Normanforderungen. Mittels einer statischen Berechnung wurde die Tragfähigkeit der Mauerwerkswand und deren wirtschaftliche Sanierungsmöglichkeiten bestimmt.

INTRODUCTION

Rehabilitation of existing buildings has grown significantly in the construction industry during the current recession. Retrofitting of structures must comply with current building regulations and have structural adequacy to resist such imposed loading as earthquakes.

The building under study was initially constructed in 1969 with a hollow tile clay block construction.

Although structural clay tile was first produced in the United States of America in about 1875, archaeological excavations have proved that structures were built with clay burnt bricks as long as 5000 years ago. In 1921 ASTM proposed a standard for hollow clay tiles. Subsequently, the use of hollow clay tile block buildings was predominant between 1940 and 1960.

The building is a clay tile block, cavity wall single storey structure with structural steel open web steel joists supporting the metal deck roofing. The structure is located in Ottawa, Canada, which is a seismic zone. Since its construction, several changes have occurred in the Canadian Building Codes (in the last 20 years).

During the construction of an addition to the building in 1992, it was discovered that several cracks had developed at beam bearing locations at the load bearing walls of the original building. During the renovation, it was found that the existing clay tile blocks were not adequately reinforced or grouted and were defective in their original construction. Although there were no major visual deficiencies noted on the outside, it was decided to review the rest of the original building for its structural adequacy to resist gravity and seismic loads according to current code requirements.

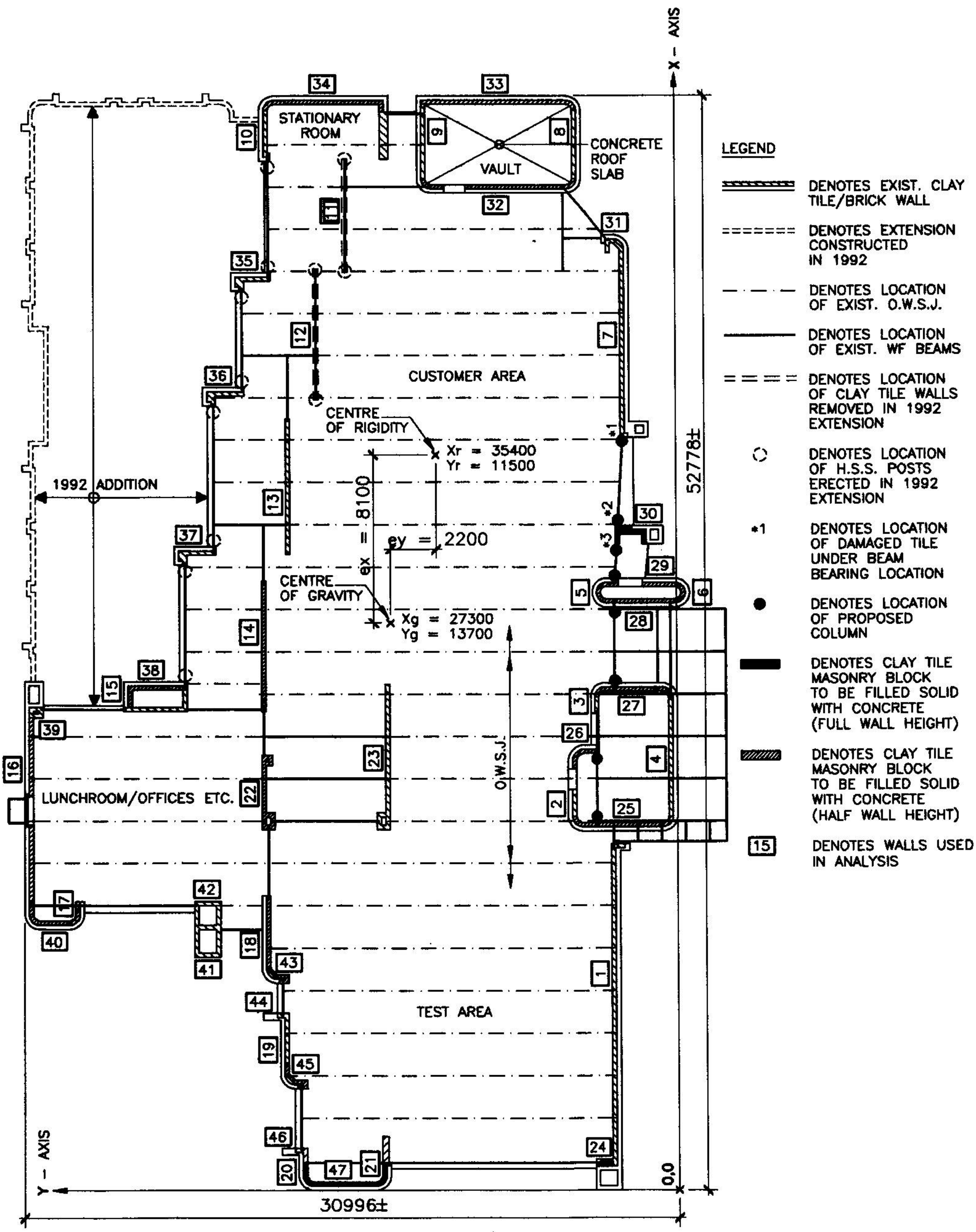
OBSERVATIONS

The layout of the building is shown on Figure 1. The walls are built with clay tile block and face clay brick as shown on Figure 3. Typical clay tile block used in the building is shown in Figure 2.

Inspection and investigation of the building revealed that there are several areas of deficient construction and inadequacies in the reinforcement of the original clay tile block masonry walls. The normal method to repair and restore the clay tile block walls would be to grout, reinforce, and restore the walls to the original design details conforming to current code requirements. The cost of such repairs would be substantial and the restoration would cause disruption to the operation of the building. Since the structure did not exhibit severe distress, it was decided to carry out a detailed structural analysis to establish the level of stresses in clay tile block masonry walls.

PURPOSE OF ANALYSIS

The purpose of this analysis was to determine if the unreinforced masonry walls were able to resist combined gravity and wind or earthquake loads in accordance with the Building Code. The current Building Code requires that load bearing and lateral load resisting masonry walls in velocity or acceleration related seismic zones of 2 and higher shall be reinforced. The Ottawa area is in an acceleration related zone of 4 and a velocity related zone of 2.



PLAN

Fig. 1 Building Layout

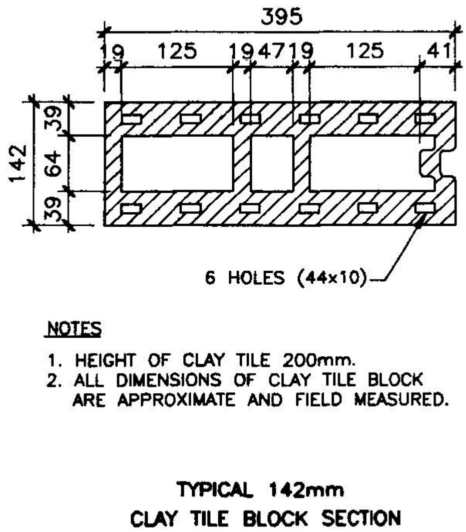


Fig. 2 Clay Tile Block

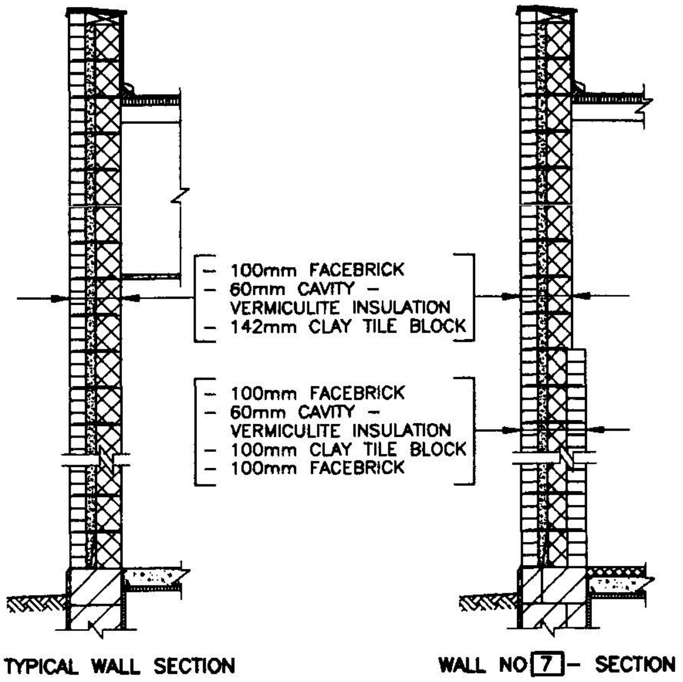


Fig. 3 Wall Sections

ANALYSIS MODEL

The wall system which resist gravity and earthquake loads is shown on Figure 1. The load resisting system consists of 45 individual walls. The exterior masonry cavity walls have been assumed to act integrally in resisting lateral forces. The clay tile block wall and brick wall are tied together with ladder type reinforcement. Gravity loads, however are supported by the loaded wythe of clay tile block masonry only.

The analysis is based on a relative wall stiffness method. Torsional effects due to horizontal forces are adequately dealt with by a stiffness matrix of the composite walls at various locations, as shown on Figure 1. Calculations indicated that seismic force controlled the analysis.

The horizontal component of earthquake load at the base of the structure V_e is determined from the following equation:

$$V_e = V \cdot S \cdot I \cdot F \cdot W \cdot \text{ as per O.B.C. 4.1.9.1 (5)} \quad [10]$$

Working stress design is considered in the evaluation of stresses to be compatible with the age of construction.

The total horizontal seismic forces along the building are distributed to walls based on their relative stiffness.

$$H_i = (K_i/\Sigma K) \cdot V \quad [8]$$

The design lateral earthquake force at the base of structure V = 1,190 kN. The design eccentricities are computed to obtain torsional moments in the orthogonal direction. The horizontal force in the walls (H_T) caused by the torsional moments (M_{tx}) is determined by the following equation:

$$H_T = [K \cdot d^2/\Sigma(K \cdot d^2)] \cdot M_{tx}/d \quad [8]$$

where d is the distance from the centre of gravity of the wall to the centre of rigidity of the structure.

The axial, flexural and shear stresses are computed. The critical stresses at various walls are shown in Table 1. The calculated stresses are compared with allowable stresses noted in Table 2 and the overstress at various wall locations are established.

WALL NO.	CALCULATED STRESSES					
	MAX. AXIAL STRESS (MPa)	MIN. AXIAL STRESS (MPa)	COMP. STRESS / ALLOW. STRESS	TENSILE STRESS / ALLOW. STRESS	SHEAR STRESS (MPa)	SHEAR STRESS / ALLOW. STRESS
14	0.311	−0.041	0.758	0.292	0.068	0.486
16	0.262	−0.076	0.640	0.541	0.117	0.834
18	0.343	−0.029	0.837	0.208	0.045	0.321
22	0.409	0.005	0.997	–	0.040	0.287
25	0.380	−0.105	0.927	0.751	0.131	0.938
26	0.311	−0.046	0.758	0.326	0.014	0.099
27	0.385	−0.068	0.940	0.484	0.102	0.729
28	0.374	−0.097	0.912	0.695	0.085	0.610
29	0.343	−0.094	0.837	0.672	0.084	0.599
30	0.452	0.065	1.103	–	0.012	0.084
32	0.308	−0.138	0.752	0.986	0.118	0.845
33	0.304	−0.140	0.741	1.000	0.119	0.850
34	0.295	−0.142	0.719	1.016	0.100	0.717
38	0.292	−0.137	0.713	0.977	0.047	0.332
40	0.351	−0.069	0.857	0.490	0.064	0.458
45	0.316	−0.089	0.770	0.635	0.016	0.114
47	0.438	−0.131	1.068	0.935	0.118	0.840

Notes:
Allowable Shear Stress = 0.14 MPa (15psi x 1.333 = 20psi, see Table 2 below)
Allowable Compressive Stress = 0.41 MPa (60psi)
Allowable Tensile Stress = 0.14 MPa (15psi x 1.333 = 20psi, see Table 2 below)
1 MPa = 145.04 psi

TABLE 1

ALLOWABLE STRESSES IN UNIT MASONRY					
CONSTRUCTION	ALLOWABLE COMPRESSIVE STRESSES (psi)			ALLOWABLE STRESSES IN SHEAR OR TENSION IN FLEXURE (psi)	
	MORTAR			MORTAR	
	TYPE M	TYPE S	TYPE N	TYPE M OR S	TYPE N
Cavity walls, solid and hollow units	70 (1)	60 (1)	55 (1)	15 (2)	10 (2)
	(1) On gross cross-sectional area of wall minus area of cavity between wythes. The allowable compressive stresses for cavity walls are based upon the assumption that the floor loads bear upon but one of the two wythes. When hollow walls are loaded concentrically, the allowable stresses may be increased by 25 per cent.			(2) Stresses may be increased one third, due to wind or earthquake either acting alone or when combined with vertical loads.	

Note: Information shown in Table 2 was obtained from 'Brick and Tile Engineering' by Harry C. Plummer.

TABLE 2

CONCLUSIONS

The analysis pinpointed areas of overstress due to earthquake loads. The results of the analysis coincided with the problem areas and overstressed locations in the field. It was also evident that the stress levels were not critical in several locations; hence those areas did not need to be reinforced to match the original structure as detailed.

Only areas overstressed would be repaired and reinforced to withstand code imposed loads by this analysis approach. The method followed by this approach of analysis would save a considerable amount of money (approximately C$200,000.00), downtime and inconvenience to the operation of the building and clients.

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