Studies on the Seismic Resisting Behaviors of Composite Concrete Block Masonry Wall(複合コンクリートブロック組積造の耐震性に関する研究)

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号	3055
発行年	2002
URL	http://hdl.handle.net/10097/8327

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学 位 授 与 年月日	平成 15 年 3 月 24 日
学位授与の根拠法規	学位規則第 4 条第 1 項
研究科、専攻の名称	東北大学大学院工学(博士課程) 都市・建築学専攻
学 位 論 文 題 目	Studies on the Seismic Resisting Behaviors of Composite Concrete Block Masonry Wall (複合コンクリートブロック組積造の耐震性に関する研究)
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論文内容要旨

CHAPTER 1- INTRODUCTION

This chapter presents background information about the nature of problems. Objective of study and research scope of this study are also described.

CHAPTER 2- REVIEW OF PREVIOUS RELATED RESEARCH

This chapter provides the information about the development of the composite concrete block masonry wall and rigid body spring model. Constitutive model of the materials and mesh formations adopted by previous researchers are also reviewed.

CHAPTER 3- TEST SPECIMEN AND LOADING SYSTEM

This chapter describes the details of test specimen of composite concrete block masonry wall and loading system, as shown in Fig.1 and Fig.2 respectively. Composite block masonry wall consists of block masonry wall surrounded by the reinforced concrete beams and columns with the shear keys. The reinforced beam and columns are constructed to delay the breaking duration of the cracked block masonry wall and to improve the ductility of structure. Shear keys are constructed on the reinforced concrete columns for controlling the slip and making good bond with concrete block masonry. The test specimen was the half scale, single story and single span walls but the actual sized concrete blocks were used. Sizes of specimen are 2690mmx2990mm. The total height of specimen was 2990mm. The joint mortars made of cement, lime and sand in the proportion 1:0.65:6.59 were used to construct block masonry wall. The size of reinforced concrete columns was 190x150mm. Four 12 mm diameter plain round bars with 4mm diameter hoops were provided in the columns. The reinforcements were not provided in vertical mortar joints

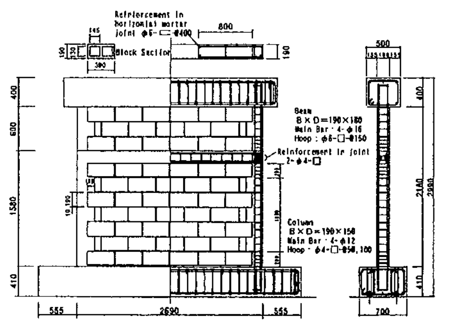

Fig.1 Test specimen

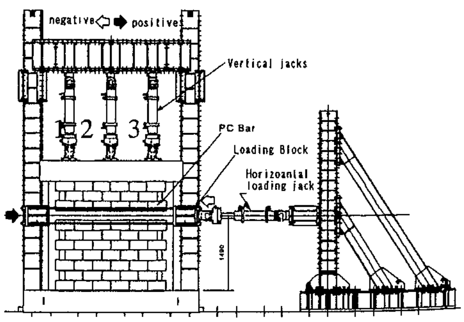

Fig.2 Loading system

of the block masonry wall, but were provided in horizontal mortar joints up to 800mm from the inner side of both columns on the alternate layer of block masonry. The strength of concrete and the yield strength of steel (SR235) were 30.5MPa and 340MPa respectively that were obtained by element tests. Fig.2 shows the loading system for performing experiments of composite block masonry wall. The constant vertical load to simulate the dead load was applied to the specimen by the three vertical hydraulic jacks for the specimen CBMW-1, CBMW-2 and CBMW-3. The specimen was subjected to the cyclic load to simulate the earthquake load by a horizontal hydraulic jack. CBMW-1 was loaded under axial stress 0.5MPa. CBMW-2 was loaded under axial stress 1.0MPa in positive direction and 0.0MPa in negative direction. CBMW-3 was loaded under axial stress 0.5MPa and moment. The axial loads developed by the vertical jacks No.1 and No.3 were changed in the positive and negative direction to generate the moment considering shear span ratio (M/QD) 1.0. Properties of joint mortar were investigated by the three-layered block test on shear and compression.

CHAPTER 4 – EXPERIMENTAL RESULTS AND EVALUATION

This chapter gives the detailed descriptions and evaluations of test results of three test specimens under the different parameters. The maximum strength, the crack patterns, slips of mortar joints, yielding of reinforcements and maximum resisting force mechanism of specimens were investigated in three specimens with different loading parameters. The maximum strength obtained by experiments for CBMW-1, CBMW-2 in positive and negative loading and CBMW-3 were 370.2kN, 551.0kN, 281.0kN and 307.0kN respectively. Fig.3 shows the load displacement relations obtained from the experiments.

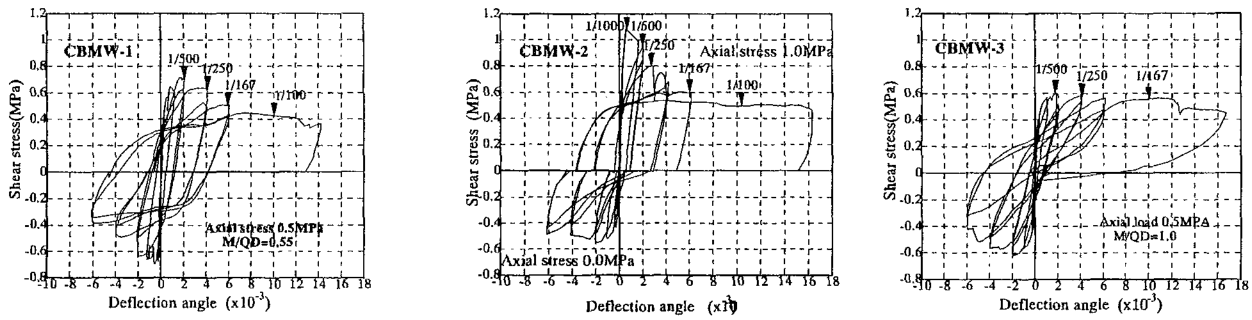

Fig.3 Load displacement relations

Figures show that after reaching the maximum load, the load begins to drop gradually with increment of displacement. The rate of the degradation of the load becomes large with the increase of axial stress. But at the large displacement level, the load is comparatively stable. The hysteresis curves are spindle shape and area within the hysteresis loop of each cycle is large.

CHAPTER 5 – RIGID BODY SPRING MODEL ANALYSIS AND COMPARISON OF ANALYZED RESULTS WITH EXPERIMENTS

This chapter presents the model formulation of rigid body spring model, constitutive models of materials used in analysis of specimen and verification of models is given through the analysis of composite concrete block masonry wall under different parameters. A Rigid Body Spring Model, which was developed by Kawai in 1976, is one of the discrete approaches. Fig.4 shows the basic concept of rigid body spring model. This model consists of the finite numbers of rigid bodies connected with normal and shear springs along its two neighboring boundaries. Three degrees of freedoms are defined at the each center of rigid body i.e two transitional and one rotation. Each side of rigid body is considered as a boundary

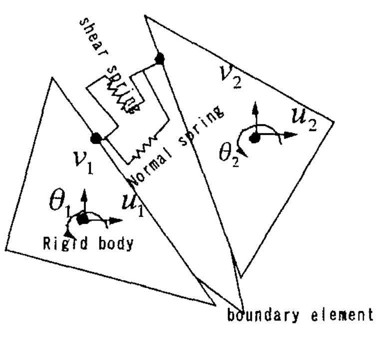

Fig.4 RBS Model

element, where two springs assumed to be placed, stiffness of which is determined using the physical properties of the concrete, mortar joints and reinforcement. This model is very suitable for the analysis of the structures having discontinuities in material properties. The models have flexible formulations to express the behaviors of cracks, slips and compressive collapses of the used materials concrete and block and we can easily know the failure modes and the stress distribution in the each boundary of rigid body.

The relative displacements of rigid bodies are defined in normal and shear spring given by Eq. 1.

$$\begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} = [B(x,y)]\{u_1, v_1, \theta_1, u_2, v_2, \theta_2\}^T \quad \text{.....(1)}$$

The stresses in the normal and shear springs is defined by Eq. 2

$$\begin{Bmatrix} \sigma_n(x,y) \\ \tau_s(x,y) \end{Bmatrix} = [D]\begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} \quad \text{.....(2)}$$

Where,

$$[D]^T = \begin{bmatrix} k_n & 0 \\ 0 & k_s \end{bmatrix}, \quad k_n = \frac{E}{(1-\upsilon^2)(h_1+h_2)}, \quad k_s = \frac{E}{(1+\upsilon)(h_1+h_2)}$$

k_n, k_s - Stiffness of normal and shear spring, E- Tangential modulus of elasticity, υ - Poisson's ratio and

h_1, h_2 - Perpendicular distance between boundary and center of rigid body.

The element stiffness of springs in the boundary element are defined by the Eq.3

$$[K] = t\int_S [B]^T [D][B]ds \quad \text{.....(3)}$$

Where, t- Thickness of element, s- Variable length of element boundary

Comparisons of test results and RBSM analysis results, in terms of load displacement relations, load strain relation of reinforcement, crack patterns, stress distributions in each boundary element, load relative displacement of block units in block masonry wall, are also done in this chapter. Fig.5 shows the comparisons of load displacement relations between tests and analyzed results, measured at the center of the middle reinforced concrete beam.

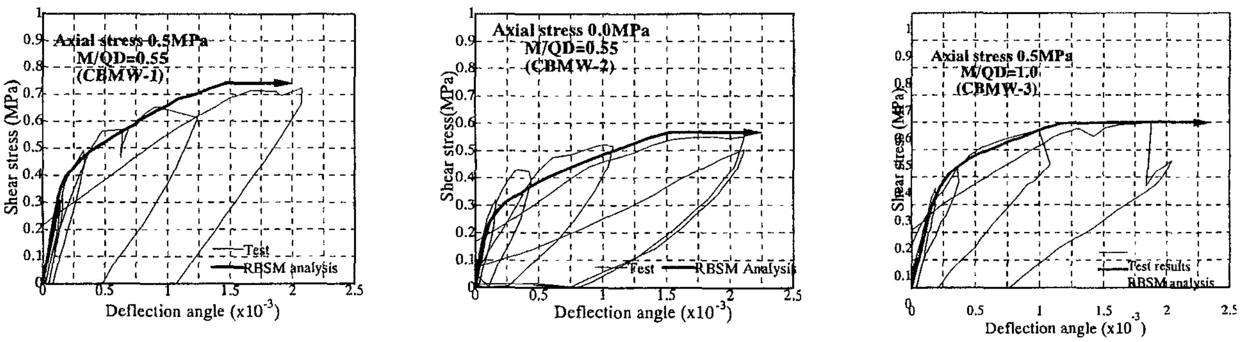

Fig.5 Load displacement relations

From the figures, it is observed that the analyzed results by rigid body spring model are consistent with the experimental results for different cases of loadings.

CHAPTER 6 - DETERMINATION OF YIELD LINE AND PARAMETRIC STUDIES

This chapter presents the study of failure mechanism yield line and its effect on the maximum shear strength. To study the effect of the failure mechanism yield line on the maximum shear strength, four analytical models, which have different failure mechanism yield line, are analyzed using the very simplified models of specimen CBMW-1. According to the upper bound theory, the lower value of load displacement relation obtained by using simplified models closed to the observed one. Maximum shear strength of test specimen under different loading condition and shear span ratio using failure mechanism yield line are also investigated. Moreover, the analyzed results obtained by analysis considering the simplified models are compared with the experimental observation. It is seen that the analyzed results using simplified models coincided with experimental results.

Parametric studies are also done in this chapter to investigate the effects of axial load and shear span ratio on the maximum strength of composite block masonry wall. It is known that the maximum strength of composite block masonry wall ratio is decreased gradually with increasing shear span ratio. It is also cleared that the maximum strength of composite block masonry wall is increased gradually with increasing axial stresses.

CHAPTER 7 – SIMPLIFIED SEMIEMPIRICAL SEISMIC DESIGN FORMULA

In this chapter, the simplified semi-empirical seismic design formulas to predict the cracking and ultimate strength and corresponding displacements are discussed. The strength obtained by simplified semi-empirical seismic design formulas, proposed by Dalian University of Technology, China are compared with test results and the analytical results obtained by rigid body spring model analysis under various parameters The strength formulas proposed by Dalian University of Technology predict well the effect of axial stress on maximum strength of composite concrete block masonry wall with some margin. Fig.6 shows the load displacement relations under different parameters. The calculated results by semi empirical formulas, in terms of the load displacement relations, agreed well with the observed one. These formulas satisfy appropriate accuracy for engineering practices.

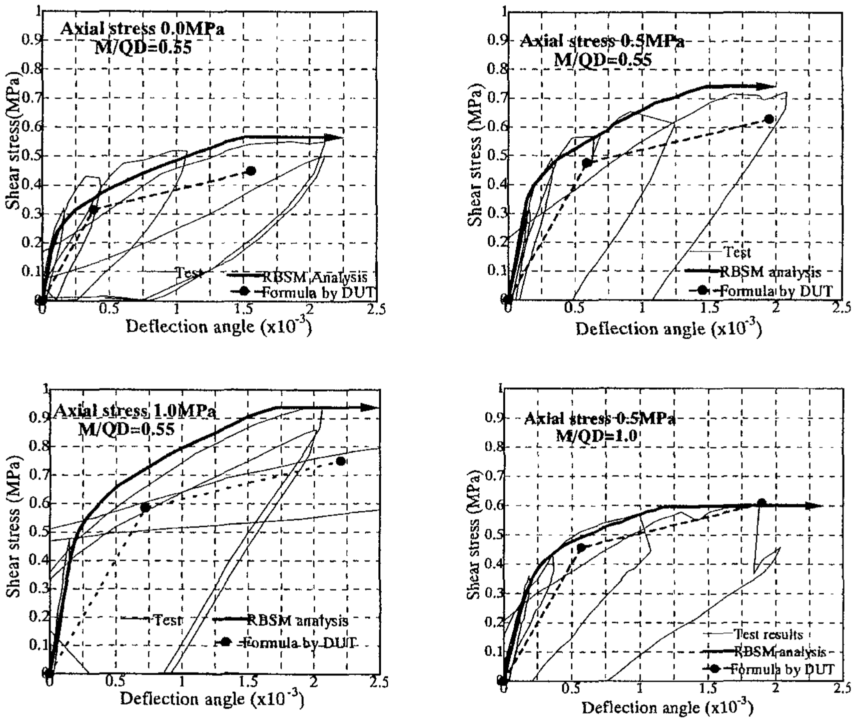

Fig.6 Load displacement relations

CHAPTER 8 – CONCLUSIONS

This chapter summarized the observations, findings and remaining problems to be solved in future.

From the test results of composite concrete block masonry wall, their non-linear seismic behaviors are made clear. A new analytical method was proposed using rigid body spring model. The analyzed results obtained by rigid body spring model are compared to the experimental results. The strength obtained by semi empirical seismic design formulas that proposed by Dalian University of Technology, China are consistent with tests and analytical results except a case, where shear span ratio 1.5. In this case, the bending influence factor used in the simplified strength formulas should be studied experimentally. The calculated results by semi empirical formulas, in terms of load displacement relations, agreed well with the observed one. These formulas satisfy appropriate accuracy for engineering practices.

論文審査結果の要旨

中国、東南アジア、南米などでは、経済的理由から無筋のブロック造建物が主に住宅用として多数建設されているが、その脆弱性のために地震が発生すると多くの人命が失われている。本論文では、無筋のコンクリートブロック造を鉄筋コンクリート柱梁で拘束して耐震性を向上させた複合積組造耐震壁を対象として静的載荷実験を実施するとともに、解析による検討を行ったもので、全８章よりなっている。

第１章は序論である。

第２章では、ブロック造に関する既往の研究と、本論文で用いた剛体バネモデルを中心とした解析法に関する既往の研究を概説し、本研究の位置付けを示している。

第３章では、本研究に用いた試験体と静的載荷実験の方法を示している。さらに、試験体は、中国で提案された複合積組造を対象としているので、中国より輸入したコンクリートブロックとそれらを接合するモルタルの特性を、３ブロック要素試験体の軸圧縮載荷実験およびせん断力載荷実験結果から明らかにしている。

第４章では、実験より得られた複合積組造壁の荷重変形関係より、ひび割れ後も靭性があり、繰り返し載荷時には比較的履歴面積が大きくエネルギー吸収能力があることを明らかにしている。さらに、軸力とせん断スパン比をパラメータにした実験を行うことによりそれらが最大耐力に与える影響を示している。

第５章では、剛体を結ぶ境界要素に弾塑性特性を集約して表現する剛体バネモデルによる弾塑性解析手法を示し、本実験結果に適用して荷重変形、応力分布、各部変形をよく追跡できることを明らかにし、本研究のようなモルタル接合部で破壊するブロック造構造物を解析するには最適なモデルであることを述べている。

第６章では、上界定理に基づき、剛体バネモデルにおける降伏線位置をパラメータにして解析を行い、実状に近い降伏線を求め得ることを示している。また、軸力、せん断スパン比の影響を解析により明らかにしている。

第７章では、中国で提案されている簡便な経験式の適合性を明らかにするために、ひび割れ耐力、最大耐力、荷重変形関係について、実験結果および剛体バネモデル結果と比較検討を行い、一般的な５階建までは概ねよい近似を与えることを示している。ただし、８階建程度の高層の場合には剛体バネモデルによる解析結果と比べるとやや危険側となるので、さらなる実験的研究の必要性があることを指摘している。

第８章は結論である。

以上要するに、本論文は、要素実験および耐震壁の静的繰り返し載荷実験を実施して、複合積組造耐震壁がよい耐震性能を有することを明らかにするとともに、剛体バネモデルによりその弾塑性挙動をよく追跡できることを示しており、世界で多数建設されている無筋ブロック積組造建物の耐震技術の向上に資するとともに建築構造学の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。