Shape optimization of latticed blocks for seismic retrofit of building frames

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Summary

A shape optimization approach is presented for latticed blocks that are assembled as a wall used for seismic retrofit of building frames. The existing beams and columns, as well as the members in blocks, are modeled using beam elements. The negative effect on the existing beams and columns, such as increase of shear and axial forces due to installation of the blocks, are reduced by optimizing the thickness and location of members in the blocks. It is shown that various shapes can be generated by solving nonlinear programming problems considering structural weight, stiffness, and contact force against the existing frame members.

Keywords: Seismic resistant wall, seismic retrofit, building frame, contact force

1. Introduction

Various methods have been developed, including passive dampers and base isolation, for seismic retrofit of building frames. Among them, installation of the earthquake-resistant wall to the existing frames is an efficient approach in view of business continuity of an office building. If we construct walls using latticed blocks, we can have much ventilation and transparency compared with the solid walls. However, in the conventional latticed blocks, shapes of members and openings are fixed[1], and the interaction between the blocks and existing frames is not appropriately incorporated in the process of seismic retrofit.

In this study, precast latticed blocks are utilized for seismic retrofit of RC building frames. The shapes (topology and geometry) of the blocks are optimized under various constraints. The total structural volume, story shear force under specified interstory drift angle, contact force between the blocks and existing frames, etc., are considered in objective function and constraints. It is shown in the numerical examples that various shapes can be found using the proposed method, and the story stiffness is effectively improved, while reducing negative effect on the existing frame members.

2. Models of latticed blocks and frame members

We consider a latticed block as shown in Fig. 1 for seismic retrofit of building frames. A wall is constructed by assembling the unit in Fig. 1, which has the size 1000 × 2000 (mm). Fig. 2 shows a wall consisting of eight units. Specification of the FRP members of blocks is listed in Table 1, where *width* is the size in the perpendicular direction to the plane, and *thickness* is the size in plane. Furthermore, *boundary* refers to the members along the boundary of the unit in Fig. 1, and the *lattice* corresponds to the members in the internal region of the unit.

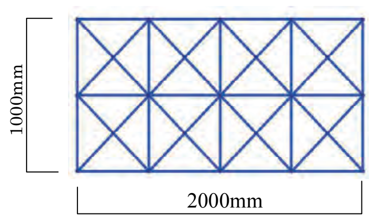

Fig. 1: A unit of latticed block.

A frame analysis program called OpenSees [2] is used for static response analysis. The existing frame is subjected to the forced displacement corresponding to inter-story drift angle of 1/200 and the stiffness of the wall assembled with blocks is evaluated from the total horizontal reaction force at the supports.

Table.1: Specification of block members.

	Width	Thickness	Cross-sectional area	Moment of inertia of area	Young's modulus
	B (mm)	T (mm)	A (mm ^{2})	I (mm ^{4})	E (N/ mm ^{2})
Boundary	150	10	1500	1.25×10^4	20000
Lattice	150	2…100	300…15000	1.0×10^2 … 1.25×10^7	20000

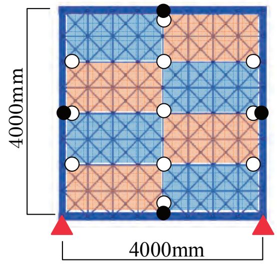

Fig. 2: Basic configuration of analysis model.

3. Topology optimization problem

We optimize the configuration of blocks under constraints on static responses considering interaction between the blocks and frame members. The conventional ground structure method is used; i.e., the locations of nodes and members that can exist are specified as shown in Fig. 2, and the thicknesses of lattice members of the block are optimized, while keeping the widths constant. Note that the width and thickness of the boundary members have specified values to prevent removal of such members.

The lattice members of eight units are classified into m groups to preserve symmetry conditions with respect to the center lines in horizontal and vertical directions. The vector of thicknesses of members in m groups is denoted as $\boldsymbol{x} = (x_1, \ldots, x_m)$. The upper and lower bounds for x_i are 100 and 2 (mm), respectively, and the member corresponding to the lower-bound thickness after optimization is to be removed.

The standard model consists of the lattice members that have thicknesses equal to their upper bounds; accordingly, it has the maximum structural volume. Let V_0 (m^3), R_0 (kN), and C_0 (kN), respectively, denote the total volume of boundary and lattice members (simply called the volume of block members), the total of horizontal support reaction force, and the total of normal contact force to the existing upper beam of the standard model. Note that the normal contact force is related to the additional shear force of the beam. These values are used to define the bounds in the following three problems. In the following, *total* is omitted where no confusion is expected.

Problem 1 is “Minimization of volume of block members”, Problem 2 is “Maximization of horizontal support reaction force”, and Problem 3 is “Minimization of normal contact force to existing upper beam”.

Table 3 shows the solutions of optimization problems. In the table, ▒ shows constraints; upper bounds for $V(\boldsymbol{x})$ and lower bounds for $R(\boldsymbol{x})$.

Optimization library called SNOPT Ver. 7 [3] is used for optimization. Optimization technique is the sequential quadratic programming, and the sensitivity coefficients are computed using finite difference approach.

Table.3 Solutions of optimization problems.

	$V(\boldsymbol{x})$ (m^3)	$R(\boldsymbol{x})$ (kN)	$C(\boldsymbol{x})$ (kN)
Standard	2.03	312.0	119.1
Problem 1	0.547	290.0	97.91
Problem 2	0.600	291.4	98.47
Problem 3	0.600	282.3	80.28

4. Conclusion

Various shapes of latticed blocks can be generated by solving nonlinear programming problems considering structural volume, shear stiffness, and contact force against the existing frame members.

References

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