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Response Evaluation of Stairways in RC Frames Under Earthquake Ground Motions

S.Fallahi[1], M. Alirezaei[*2]

[1] MSc student, Department of Civil Engineering, Malayer Branch, Islamic Azad University, Malayer, Iran

[*2] Department of Civil Engineering, Malayer Branch, Islamic Azad University, Malayer, Iran

M.Alirezaei@iiees.ac.ir

Abstract

Stairways, the primary vertical emergency exit routes in multistory buildings, are critically important for egress and access during earthquakes and fires. Seismically damaged stairways have delayed evacuation, impeded efforts of rescuers and fire fighters, complicated salvage and restoration operations, and resulted in deaths and injuries. The seismic behavior of typical stairway systems is not well understood, and few code provisions are directed toward the problem of stairway design. This paper initiates the study of the performance of stairways in earthquakes. The past seismic performance of stairways is reviewed and classified by damage type.

Keywords: Reinforced concrete, Stairwell, Pushover Analysis.

Introduction

Stairways are essential building components serving critical functions of emergency access and egress following earthquakes and fires. Stairways also may significantly affect the seismic response of Structural systems. Past earthquakes have exposed a wide variety of problems and failures related to stairway/structure interactions. Present architectural and structural engineering practices may not address these interactions adequately [1]. Design concept is an impressive term that we use to describe the intrinsic essentials of design. The concept encompasses reasons for our choice of design loads, analytical techniques, design procedures, preference for particular structural systems, and of course, and our desire for economic optimization of the structure. A formwork system is defined as ‘‘the total system of support for freshly placed concrete including the mold or sheathing which contacts the concrete as well as supporting members, hardware, and necessary bracing. “Formwork system” development has paralleled the growth of concrete construction throughout the twentieth century [2]. As concrete has come of age and been assigned increasingly significant structural tasks, formwork builders have had to keep pace. Form designers and builders are becoming increasingly aware of the need to keep abreast of technological advancements in other materials fields in order to develop creative innovations that are required to maintain quality and economy in the face of new formwork challenges. Stairways play significant roles in building performance during earthquakes due to dynamic interactions with primary structural systems and the occurrence of unanticipated and undesirable responses.[3] Damaged stairway adversely affect evacuation and rescue. Fire Fighting, salvage, and restoration. Severe earthquakes may require that building occupants rescue there selves, elevators may not be functional, and imminent secondary hazards such as fire or flooding may make immediate evacuation imperative. Stairways are permanent, rigid, and frequently heavy elements often extending the full height of the building. Connected directly or indirectly to the primary structure. In multi-story fire-resistive buildings, stairs are typically constructed of reinforced concrete, steel, or a combination of those materials. The stairway system includes stair flights and landings, enclosure walls, doors and windows, lighting, ventilating systems, standpipes, and other services. Stairways may be open monumental staircases, enclosed fire stairs, exterior fire escapes, or service stairs [4].

Although many stairways in multi-story buildings have withstood strong. Seismic shaking satisfactorily, other stairways have exhibited a wide range of significant damage. The most critical life safety issues are interference of stairway structural behavior with the building’s overall seismic response which results in collapse, and interference of damage with emergency exiting and rescue. The typical diagonal brace-like configuration of stairways can, at one extreme, increase the overall lateral stiffness of the structure and significantly alter the dynamic character of the structure as a whole, or, at the other extreme, simply modify local response behavior of the structural element to which it is attached [5]. The change in overall lateral and torsional stiffness often results in higher seismic force levels than would be anticipated by considering the primary structure alone and, in some cases, has jeopardized the stability of the whole structure. Damage to stairways can also result. Stairway landings connected to columns at mid-height have added unexpected stiffness and created "short columns," resulting in brittle shear failures (Fig. 1).

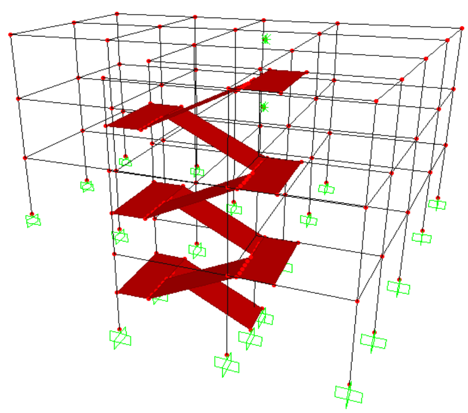

Fig.1 Stairway landings connected to columns at mid-height view

"Short beams" have been created by stair flight connections. High local shear stresses have occurred in floor diaphragms due to restraint by stair Enclosure walls. Stairs and walls have introduced torsional eccentricities, causing local failures of primary structural elements. Out-of-phase relative responses of stair towers and structures have caused pounding and damage to separation Joints, and stair towers have overturned. Damage to stairway has included failures of brittle enclosure materials which have littered or broken treads, cracking and spelling of concrete at landings and walls, jammed exit doors, broken glass, dislocation of nonstructural components such as light fixtures or seismic joint cover plates, and disruption of building services. In some cases stairways have been places of unusable. Some Stairways have been places of refuge during shaking; other stairways have caused injuries and fatalities. According to current Iranian codes, earthquake action is not considered in the structural design of stairwells in all kinds of buildings, whether framed structures, masonry structures or mixed structures. The basic components of a stairwell, such as staircase treads, landing beams and platforms, are designed to support the gravity loads. It is known that the seismic response of a building is related to its orientation with respect to the direction in which earthquake waves propagate. When a building is mainly subjected to horizontal seismic forces in the transversal direction, i.e. parallel to the tread depth, stairwell mainly behaves analogous to diagonal strut, and partially prevents the building from deforming laterally. On the other hand, when a building is mainly subjected to the horizontal seismic forces in the longitudinal direction, i.e. normal to the tread depth, the joints of columns and landing beams are likely to experience damage because of the floor slab discontinuity in the stairwell reducing its overall stiffness.

Modeling

ASCE 7-10 provides the following definitions for the two types of irregularities studied in this paper: 1-Vertical geometric irregularity: Exists when the horizontal dimension of the seismic force resisting system in any story is more than 130% of any adjacent story. 2-Reentrant corner irregularity: Exists when both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction. The first step of this research is the design of each structure according to the prevalent design codes: The ACI, and ASCE 7-10. Plan view of MRFs are shown in Figure 2 and 3 (for 3-7 and 10story structures).

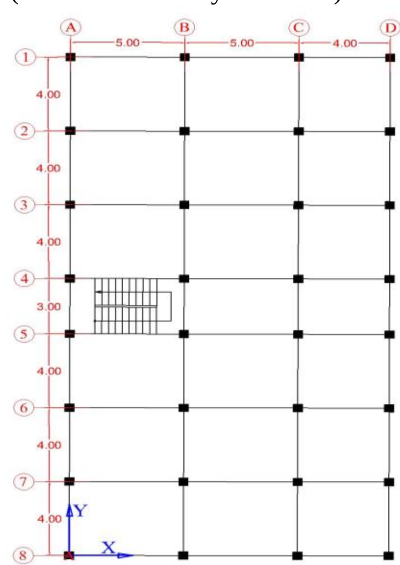

Fig.2 Plan of regular structure view, Plan number 1

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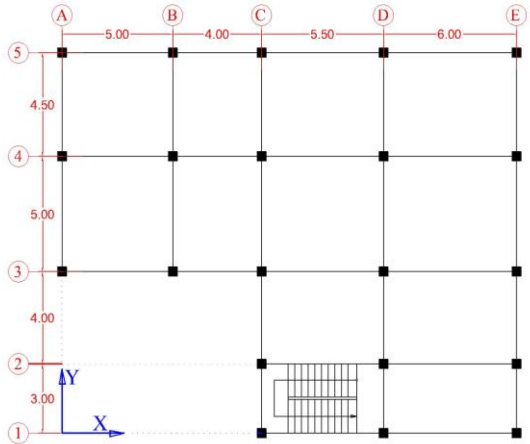

Fig.3 Plan of irregular structure view, Plan number 2

Seismic design is based on the equivalent lateral force procedure of 2800 (Iranian code of Practice for Seismic Resistant Design of Building). All other loads and load combinations are in accordance with subject 9 iranian code. The static loads considered for the design of each structure include dead, live earthquake, and wind loading. The load combinations considered for steel frame design are followed in accordance with the guidelines in 2800 iranian code. Uniform live and dead loads are assigned to each floor. A 200 kg/m^2 live load is assigned at each level. The uniform dead load consists of the self-weight of the building structure, plus an additional 75 kg/m^2 to account for partitions, ceilings, ductwork, and any additional structural items. Included in the self-weight are all steel members and a 15 cm thick concrete slab. A rigid diaphragm is assumed for each floor. Stairway can be structurally isolated as physically separate exterior towers, in enclosures mechanically isolated from the adjacent building frame, or as stairs with Sliding joints at landings and walls. Isolation demands a clear understanding of the seismic response of the building and stairway in order to estimate with sufficient accuracy the necessary separations and appropriate inter story drift. By reducing interaction through carefully controlled connections or ductile isolators, damage and hazards could be considerably lessened, although the separated Stairway would still experience accelerations. Too small separations, because of the effects of impact (pounding), could worsen structural behavior rather than improve its Separated stair tower foundations need special attention to withstand the large overturning forces which may be expected. Isolation strategies require consideration of materially weatherproofing, fire and smoke infiltration, and Maintenance to ensure effectiveness during the service life of the building. Stairways may be integrated with the primary structural system to take advantage of the inherent stiffness characteristics of the stair as well as the enclosure walls. Stiffness contributions of some stair flights and landings ray be assumed, but are usually not calculated, there being no easy method for this analysis. A stiff primary structure can protect stairways from damaging deformations. In a flexible system, integrated stairways can increase the stiffness of the structure substantially. This has advantages for controlling deformations, can result in an increase in overall lateral resistance, and may also lead to considerable increase in elastic strength. However, integration of stairway system which lack sufficient strength to contribute usefully in a flexible primary structure, may create local problems and potential hazards. For gravity load analysis a stairway is typically taken to be an independent system supported by the primary structural system in either a simple beam, fixed manner. A single-flight stair is analyzed as if it were a simple beam, considering only flexural stresses. For lateral load analysis the initial elastic contribution of typical stairways to the behavior of the "total structure" could perhaps be approximately modeled as an equivalent assembly of rigidly connected beam or slab elements or as elements of a truss. But even if such an equivalent space frame approach provides sufficient accuracy, many stair/structure total systems would have to be modeled as complete three-dimensional assemblies to correctly analyze their interactions. Complications are added by openings, enclosures, complex stair geometries, and supports. The initial elastic detailed local behavior of a stairway system may be modeled using plate finite element analysis. Such detailed modeling of stairway systems within a "total" system offers an available, albeit cost-prohibitive, approach. In an ideal earthquake resistant design and construction code: (a) the functions of stairways for regular service and emergency conditions should be stated, terms defined, and typical components identified. (b) Conceptual guidelines for exit safety should be reviewed and modified to bring a seismic safety issues forward. Present U.S. seismic codes do not contain guidelines regarding stairway system selection, design or construction. Only a few foreign building codes specifically mention earthquake resistant stairway design.

Inelastic Analyses

The pushover analysis, has been carried out by means of the SAP2000 program by taking into account the P–Delta effect. This software is one of the best softwares that has many characteristics making it the best for the finite element modeling. The analytical

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models were centerline representations of the frames for which inelasticity has been restricted to the diagonals while the elements of the backup frame were modelled as elastic beam–columns. Diaphragm action was assumed at every floor due to the presence of the slab, while Rayleigh damping corresponding to 5% of critical damping at the first two modes was adopted. Rational design should be based upon analysis to predict the response of stairway systems to expected ground motions. The reliability of these analytical methods must be demonstrated experimentally, and the cost of analysis kept within practical limits. Simple methods are needed because complex studies may not be justified economically or technically. Structural engineers may need to decide for which stairway configurations costly analytical studies are warranted, and for which stairways standard details and provisions for construction and maintenance should be developed. When a building is mainly subjected to horizontal seismic forces in the longitudinal direction, discontinuities of floor slabs in the stairwell creates stiffness discontinuities of the whole building in the longitudinal direction due to interruption of the diaphragm action. As mentioned above, the modelling of earthquake actions as lateral displacements rather than forces constitutes a more natural and rational approach. Hence, there seems to exist a solid rationale for preferring the application of displacement rather than force patterns in pushover analysis. The nonlinear static pushover Analyses, RC frames are demonstrated in Fig 4- Fig 15.

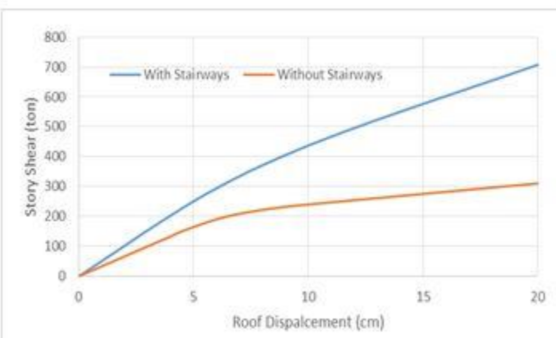

Fig.4 Pushover curves for the 3story building, Plan number 1, X direction

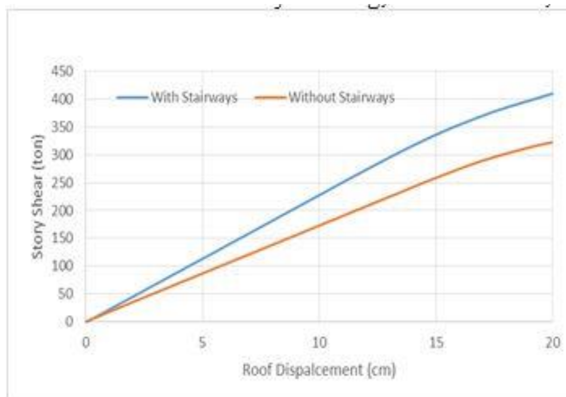

Fig.5 Pushover curves for the 7story building, Plan number 1, X direction

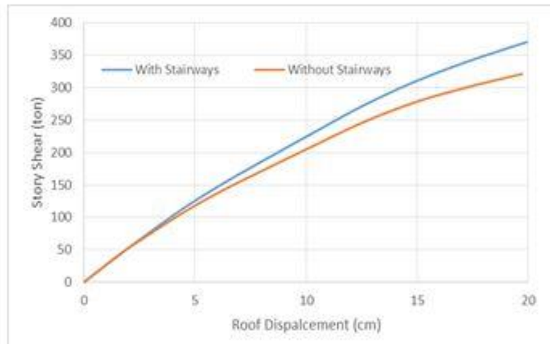

Fig.6 Pushover curves for the 15story building, Plan number 1, X direction

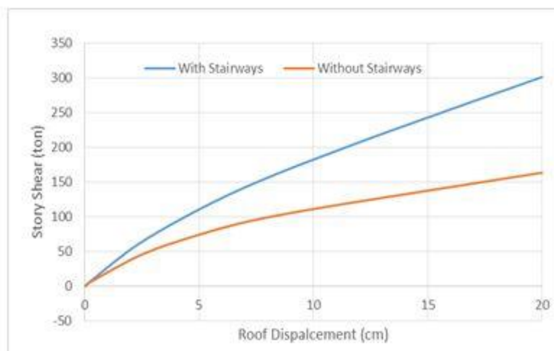

Fig.7 Pushover curves for the 3story building, Plan number 2, X direction

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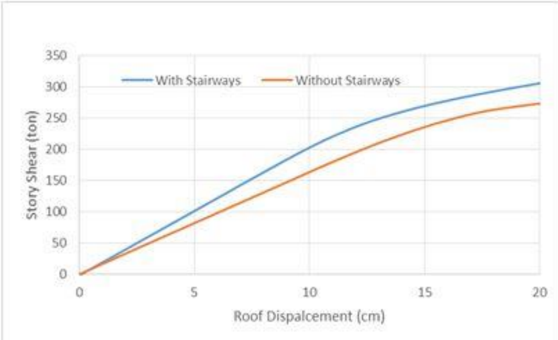

Fig.8 Pushover curves for the 7story building, Plan number 2, X direction

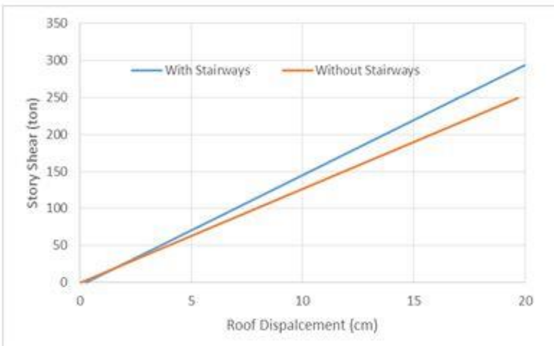

Fig.9 Pushover curves for the 15story building, Plan number 2, X direction

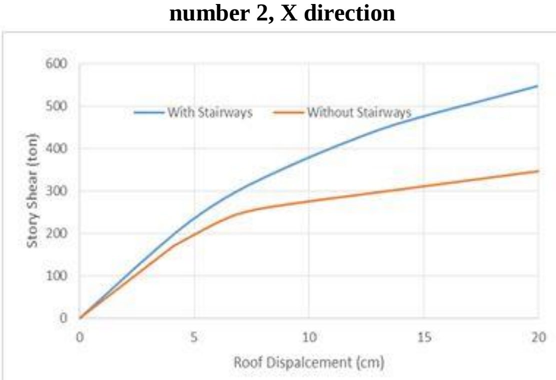

Fig.10 Pushover curves for the 3story building, Plan number 1, Y direction

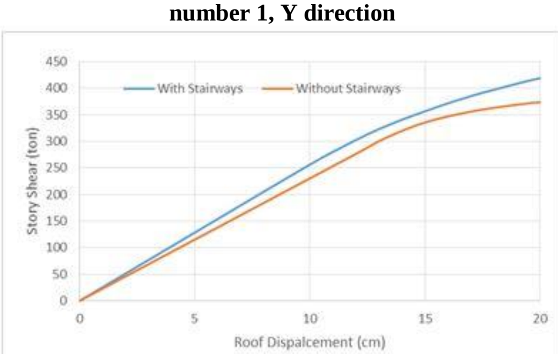

Fig.11 Pushover curves for the 7story building, Plan number 1, Y direction

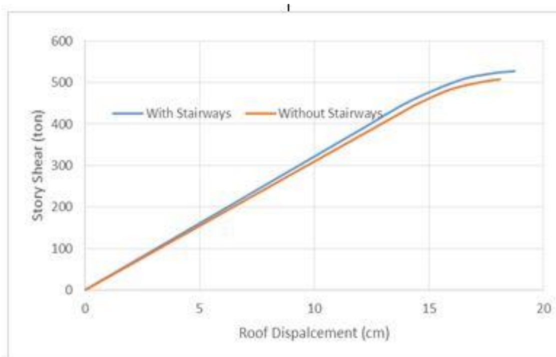

Fig.12 Pushover curves for the 15story building, Plan number 1, Y direction

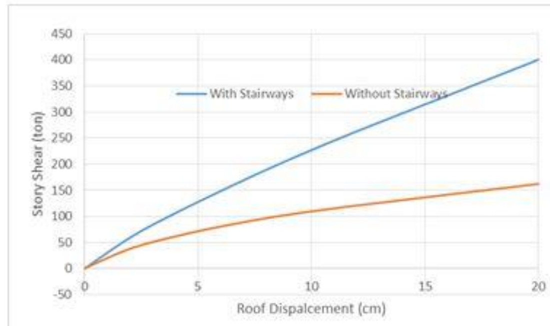

Fig.13 Pushover curves for the 3story building, Plan number 2, Y direction

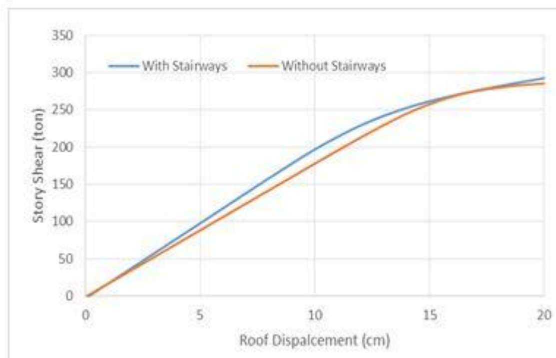

Fig.14 Pushover curves for the 7story building, Plan number 2, Y direction

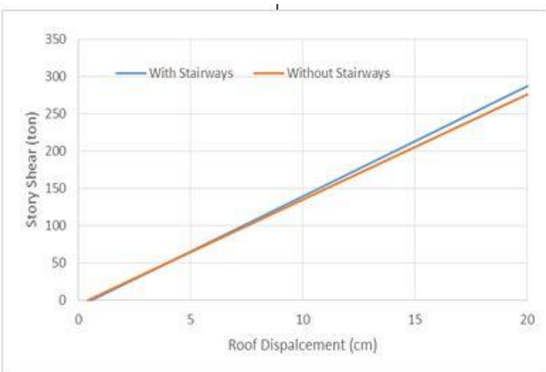

Fig.15 Pushover curves for the 15story building, Plan number 2, Y direction

Conclusions

Locations and arrangements of stairways result from design decisions on spatial organizational and functional layout, internal circulation and emergency egress. For stairway systems intentionally designed to be part of the primary seismic resistant system, stairway shafts and other service cores are best distributed to avoid undesirable torsional effects, to balance the stiffness of the resistant elements with the mass. Especially problematic are Steinway systems which act "unintentionally" as part of the primary structural system. These may significantly influence the initial elastic response of the building by their distribution and stiffness, and the inelastic response by their strength and ductility, producing unanticipated seismic behavior. Movement characteristic of stairway structures. Must relate to those of the primary structural system. Stairways may be integrated in very stiff structures which protect them from damaging deformations. Stairways in ductile moment-resistant frame structures designed to stably dissipate seismic energy, may experience large deformations. These stairs may be isolated if stiff or integrated if having flexible enclosures and flights. Either structure deformations must be limited to those which the stair system can accommodate, or the stairways must be made tougher to withstand larger deformations. These deformations should be those which are expected in the actual building under real ground motions, not just those computed according to fictitious lateral forces defined by building codes.

Collaboration of architect and engineer in preliminary design phases can resolve basic configuration issues for stairway and establish the extent of stairway/structure interaction through selection of appropriate design strategies. Design proposals should be reviewed specifically to detect potential interactions and nonstructural elements which could cause undesired effects. When possible, the adequacy of the design should be verified through realistic analyses.

Since stairways are often complex three-dimensional system integrating ting a variety of architectural, structural, electrical, and mechanical components, their seismic behavior may involve complex interactions among these components.

At present there exist no practical general analytical methods for predicting even the simplest aspects of stairway dynamic interaction with the primary structure. Few construction details for structural connections and assemblies have been experimentally evaluated for strong seismic shaking.

Architectural design would benefit from consolidation of planning concepts for building configurations and stairway locations. Seismic implications of various architectural and structural plans should he studied and published so that designers may either avoid or consciously accommodate problematic schemes. Cost-benefit analyses of different design options should be considered in relation to seismic resistance, life safety, and property damage.

Seismic codes should include guidelines and comments about problems of interactions between stairways and primary structural Systems. Omissions and ambiguities in specific requirements should be retuned so that designers using the code provisions could demonstrate the acceptability of their emergency egress schemes for earthquake hazards.

References

[1] *Bixiong Li , Zhe Wang , Khalid M.Mosalam , Xuan Wang , Zhou Wei: Analysis of stairwells performance and damage during Wenchuan earthquake, The 14th World Conference on Earthquake Engineering , Beijing, China, 2008.*

[2] *Michael N.Fardis: Seismic design, assessment and retrofitting of concrete buildings 2009.*

[3] *Catherine Roha , James W. Axley, Vitelmo V. Bertero , The performance of stairways in earthquakes, College of engineering university of California, Berkeley, California 1982.*

[4] *Computers and Structures, Inc,"Help of SAP2000 software" , http://www.csiberkeley.com*

[5] *K. Chopra, R. K. Goel, Inelastic Seismic Response of One-Story Asymmetric-Plan System: Effect of Stiffness and Strength Distribution, Earthquake Engineering and Structural Dynamics, 1990, 19: 949-970.*