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Autor: Zwicky, Peter / Bachmann, Hugo

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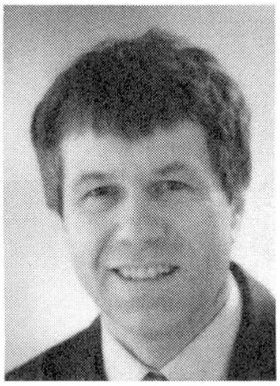
Seismic Upgrading of an Auditorium Building in Zurich

Renforcement parasismique d'un bâtiment avec auditoires, à Zurich

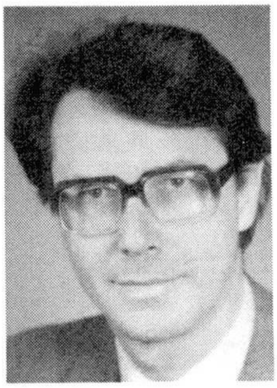
Erdbebenverstärkung eines Hörsaalgebäudes in Zürich

Peter ZWICKY
Civil Engineer
Basler & Hofmann
Zurich, Switzerland



Peter Zwicky, born in 1952, received his civil engineering degree from the ETH Zurich. He is active as a specialist for earthquake engineering and structural dynamics.

Hugo BACHMANN
Professor
Swiss Fed. Inst. of Technology
Zurich, Switzerland



Hugo Bachmann received his Dipl. Ing. and Dr. sc. techn. degrees from ETH Zurich. After practical experience with consulting and contractor firms, he returned to the ETH as Professor of Civil Eng. His and activities concentrate on RC and PC, structural vibrations and earthquake engineering.

SUMMARY

After a new assessment of the overall structural safety of an auditorium building, the seismic safety was found to be insufficient. As an upgrading measure, 30 new diagonal steel truss elements have been placed in the first floor. They support the superstructure and increase the capacity for horizontal seismic forces. The upgraded structure fulfils the current Swiss seismic code requirements.

RÉSUMÉ

La réévaluation d'un bâtiment avec auditoires a mis en question la sécurité parasismique de ce dernier. Le renforcement parasismique du rez-de-chaussée comprend 30 nouvelles colonnes diagonales en acier. Celles-ci améliorent la résistance aux forces sismiques horizontales. Le bâtiment répond ainsi aux exigences de la norme sismique suisse en vigueur.

ZUSAMMENFASSUNG

Im Rahmen der Neubeurteilung der gesamten Tragsicherheit eines bestehenden Hörsaalgebäudes wurde u.a. die Erdbebensicherheit als ungenügend beurteilt. Als Verstärkungsmassnahme sind im Erdgeschoss insgesamt 30 diagonale Stahlstützen eingebaut worden. Diese Stützen verbessern den Tragwiderstand für horizontale Kräfte aus seismischen Einwirkungen. Damit werden die Anforderungen der aktuellen schweizerischen Erdbebennorm erfüllt.

1. INTRODUCTION

The structural safety of a 20 year old university auditorium building with large lecture-rooms had to be reassessed and upgraded.

The building belongs to the university campus of the Swiss Federal Institute of Technology (ETH) at Hönggerberg in Zürich, Switzerland. Figure 1 shows a part of the building during the upgrading construction. The original building's structure before upgrading is characterized by the figures 2 and 3. It has a hexagonal layout with main dimensions of 74m x 69 m. The building's elevation is 22m above and 8m below ground level. The main structural elements are built in reinforced concrete (RC) and in steel.

Originally only the gravity load capacity had to be reassessed. But special features of the structure are a partially soft first storey and an asymmetric configuration of the horizontally stabilizing RC structural walls in this storey. Therefore, beside the vertical gravity loads the horizontal seismic forces had to be included in the structural capacity assessment.

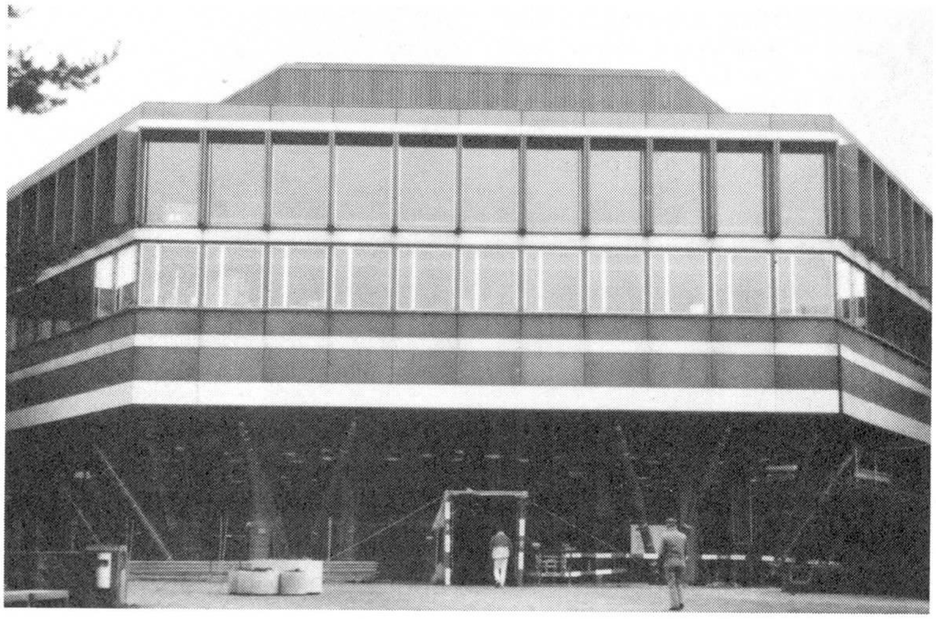


Fig. 1 View from outside towards the upgraded building (during construction). The diagonal steel trusses are the main strengthening elements

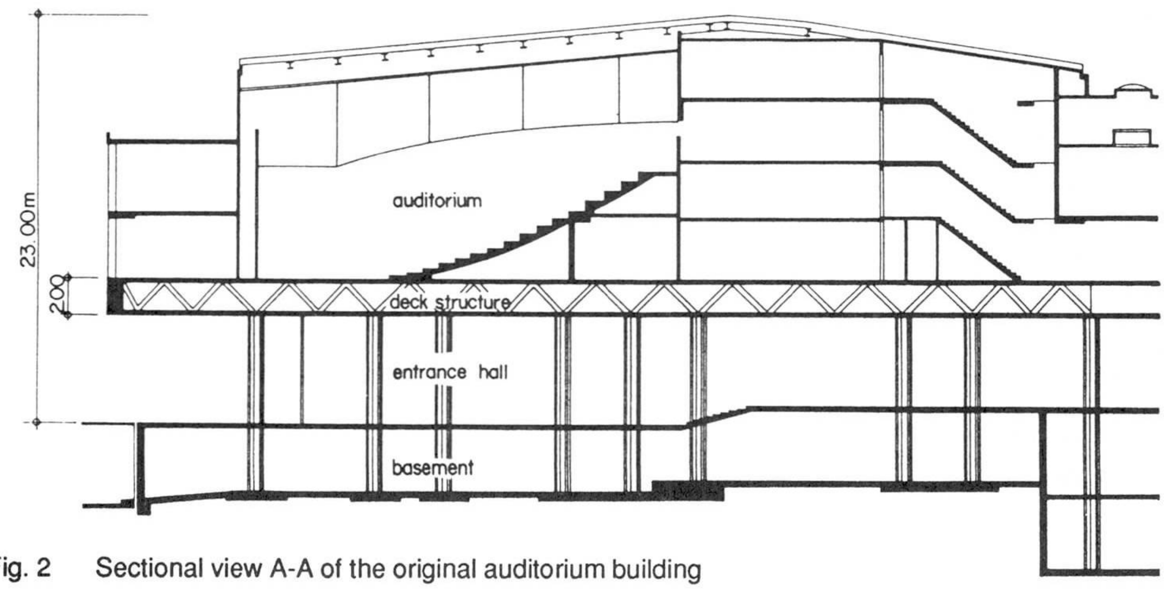


Fig. 2 Sectional view A-A of the original auditorium building

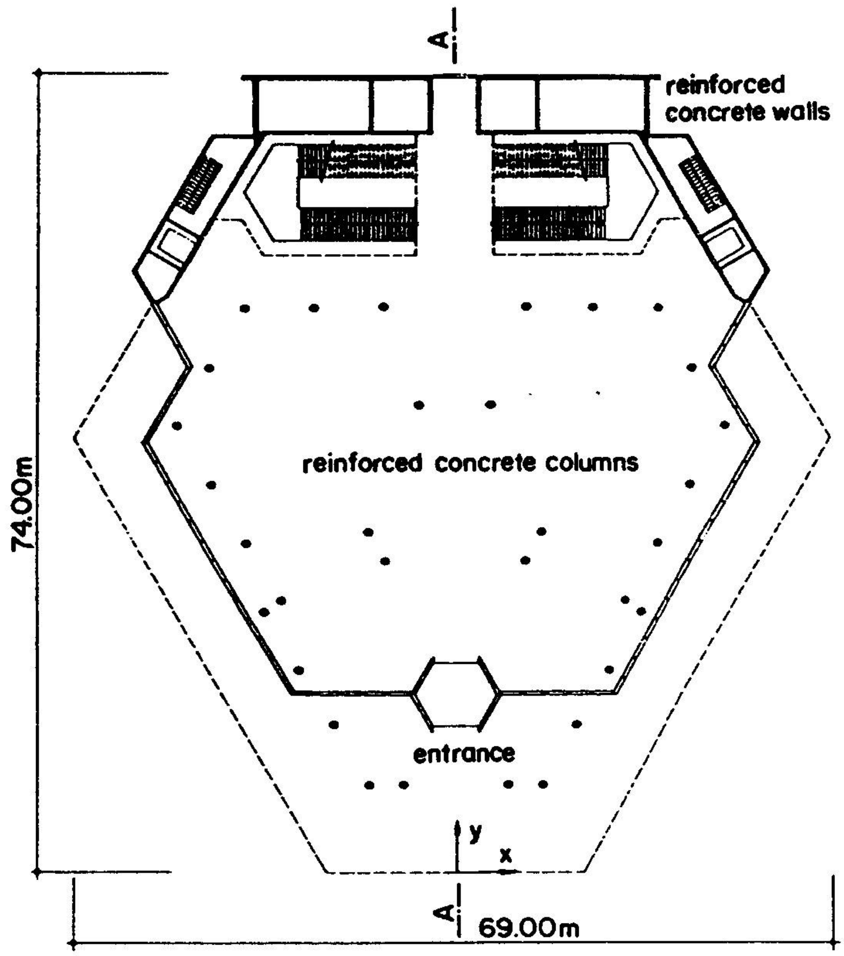


Fig. 3 Plan view of the original auditorium building: first floor

2. SEISMIC ASSESSMENT OF THE ORIGINAL BUILDING

The actual seismic requirements are defined by the Swiss Building Code SIA 160 [1]. The design earthquake has an Intensity of VI – VII (MSK-scale) and corresponds to a recurrence period of 300 – 500 years. It is defined by an effective horizontal ground acceleration of 0.06 g and by a broad-banded elastic design spectrum describing the frequency content of the expected ground motion. For buildings with the importance and the damage potential of the investigated building (building class II) the code allows moderate damage due to design earthquake, but requires sufficient structural capacity to prevent partial or total collapse.

The seismic capacity of the original building was assessed by a combined experimental and analytical investigation. Ambient vibration measurements were carried out to determine the fundamental dynamic characteristics, such as eigenfrequencies and eigenmodes [2]. The design forces were then estimated by a simplified dynamic analysis. The resistance (shear capacity) of the structural system was investigated in a detailed strength analysis.

Figure 4 shows the result of the capacity assessment: the resistance is plotted as a function of the horizontal displacement and compared to the elastic seismic force (seismic design force if a purely elastic response of the structure is assumed). The resistance calculated with help of actual material strengths turned out to be far below these forces. Hence, the code requirements can not be fulfilled by the original structure. Even if large inelastic deformations are tolerated, the available ductility would by far not be sufficient to ensure the building's integrity.

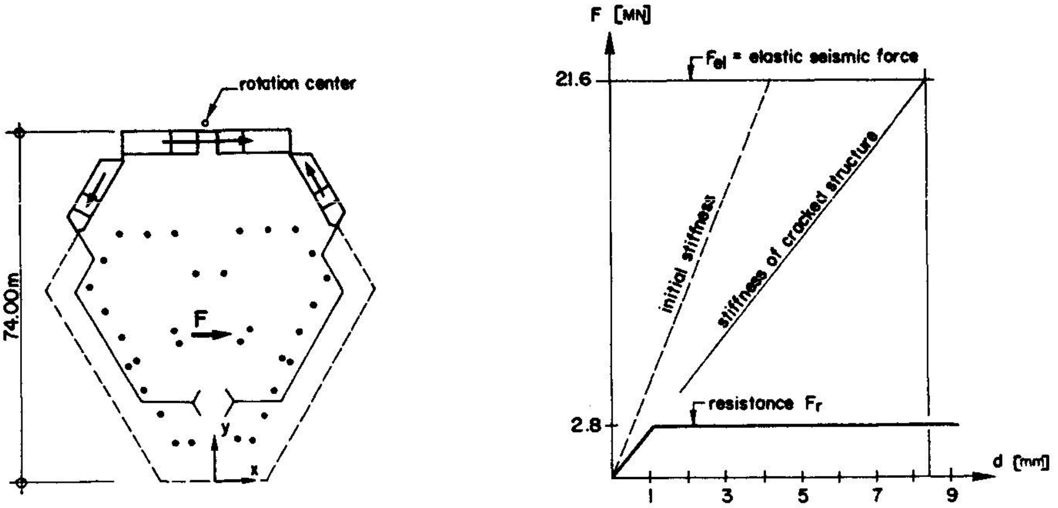


Fig. 4 Resistance to overall seismic forces (x-direction) in the first floor before upgrading (d is the horizontal displacement in the mass center, relative to the soil and foundation)

3. VARIANTS FOR STRUCTURAL UPGRADING

Ten different variants for structural upgrading, including ductile and elastic remaining constructions, were suggested and discussed. Most of them provide additional structural elements which increase the stiffness and the force transfer capacity in the first storey. The two most suitable and efficient variants are described below.

3.1 Variant «Capacity Design»

Figure 5 represents a ductile solution, based on the principles of the capacity design method [3]. The 2 RC concrete blocks with 5 ductile steel elements each, restrained in the concrete block and in the deck structure, provide additional shear capacity in the first floor. The steel elements are designed to act as plastifying link beams.

This solution would serve for seismic upgrading only. For gravity load upgrading additional elements in the hollow space of the deck structure are needed.

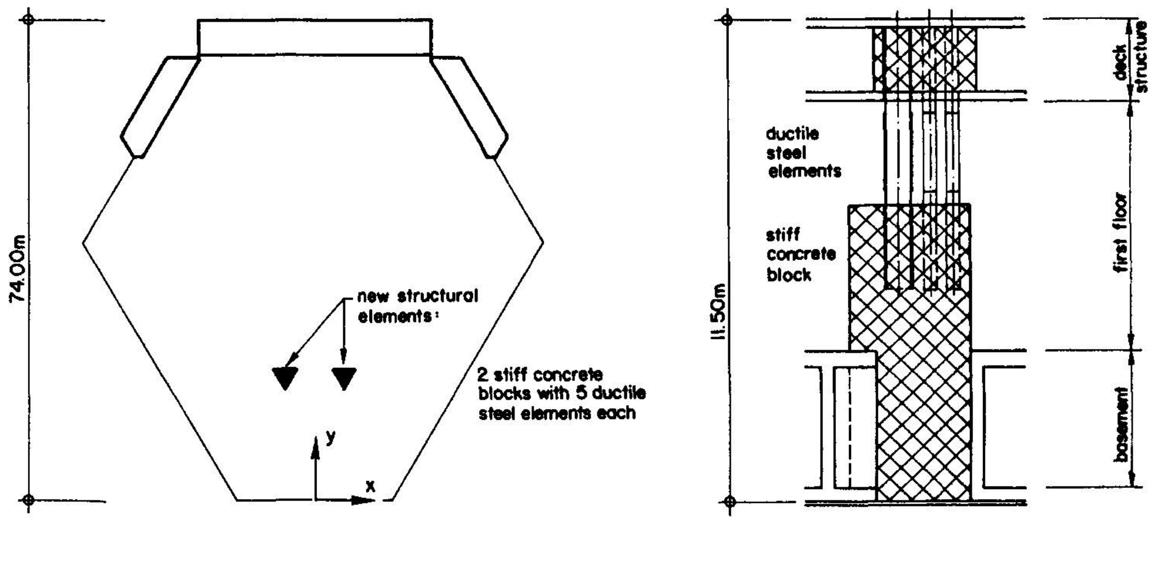


Fig. 5 Upgrading variant "capacity design" with ductile steel elements in a stiff concrete block; left: plan view; right: sectional view

3.2 Variant «Diagonal Trusses»

Figure 6 represents an "elastic remaining" solution serving simultaneously for seismic upgrading and for gravity load upgrading. The solution consists mainly of 30 diagonal steel truss elements placed outside the building to support the deck structure. The truss elements are ring profiles welded at both sides to the joint elements. The support structures at the top and the bottom of the trusses are strengthened by a reinforced concrete girder and a foundation with additional steel anchorage elements (figure 6, right). The foundation of the trusses is integrated in the basement of the building.

The trusses are designed to complement the existing structural walls in the rear part of the building. Simultaneously they enhance the gravity load capacity of the originally cantilevered deck structure.

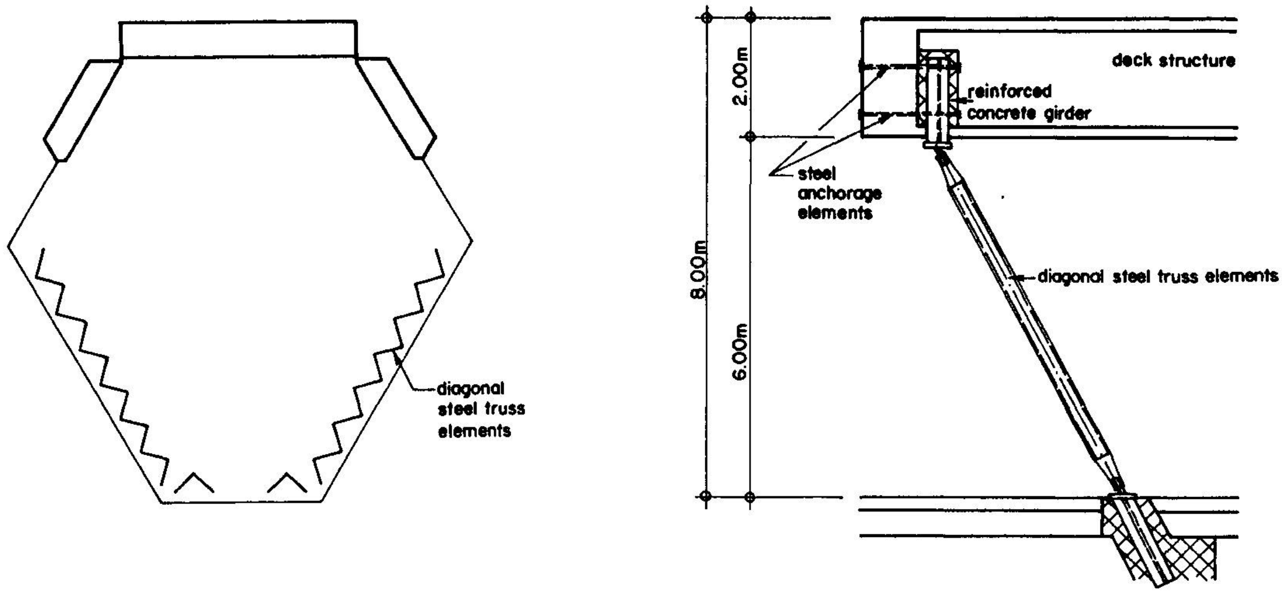


Fig. 6 Realized upgrading variant
left: plan view of new trusses right: sectional view with construction of support strengthening

3.3 Variant Choice and Arguments

After systematic comparisons and discussions between owner, architect, engineer and experts the owner decided to realize the variant «Diagonal Trusses». The main reason for this choice was that the truss elements increase not only the seismic capacity of the building but also the vertical capacity of the deck structure. The cantilever parts with minimal safety margins for vertical loads are significantly upgraded by the new supporting trusses.

With this solution it was possible to realize construction work mainly outside of the building; the lecture activities were not severely disturbed. The extremely tight time schedule for the main construction was limited to the 3-month period of the university's summer vacation 1994.

4. SEISMIC ANALYSIS OF THE UPGRADED STRUCTURE

The new steel trusses are designed to work in the range of their elastic material behaviour, also for the design earthquake. However, the interaction of the original structure with the added truss elements was investigated by a nonlinear static analysis, using the information from the previous measurements and analyses. The structure above the first floor was modeled as a rigid body, stabilized by horizontal elasto-plastic springs representing the original structural walls and the added trusses.
Figure 7 represents the model for the nonlinear static analysis with the finite element code FLOWERS [4] and the resulting force-displacement relationship for excitation in the weak horizontal direction.

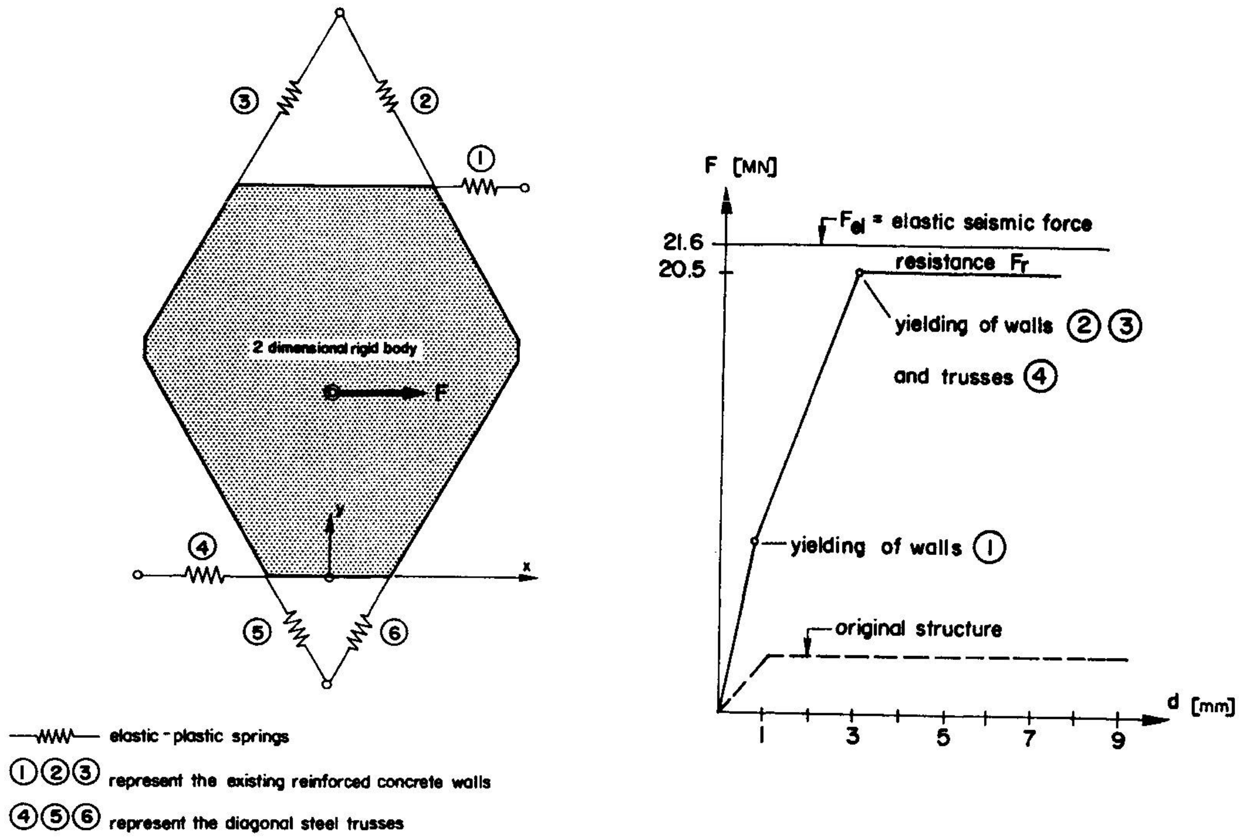


Fig. 7 Analysis model and result of seismic capacity assessment for the upgraded structure

It is obvious that the seismic resistance is effectively increased by the upgrading measures. The resistance is now only very little below the elastic seismic force, determined for purely elastic behaviour of the structure.

Compared to the original structure the first yielding is expected at a significantly higher level of seismic force. The required ductility for the design earthquake is reduced to a maximum ductility factor in the order of 2 - 3 for the RC structural walls in the rear part of the building.

The stiffness is increased by the trusses and the collapse mechanism is improved. When the elastic limits are reached in wall 1, the forces can be further increased and rearranged to the remaining structural elements. Under the design earthquake the total displacements in the mass center are limited to approximately 3 mm, relative to the soil and foundation.

5. CONCLUSION

The upgraded building fulfills the seismic requirements of the Swiss Building Code adequately.

REFERENCES

1. SWISS SOCIETY FOR ENGINEERS AND ARCHITECTS; Actions on Structures, Code SIA 160, 1989
2. SWISS FEDERAL LABORATORIES FOR MATERIAL TESTING AND RESEARCH; Report "ETH Hönggerberg, Gebäude HPH, Schwingungsmessungen", January 1990
3. PAULAY T., BACHMANN H., MOSER K.; Erdbebenbemessung von Stahlbetonhochbauten, Birkhäuser-Verlag Basel Boston Berlin, 1990
4. SWISS FEDERAL INSTITUTE OF TECHNOLOGY, INSTITUTE OF INFORMATICS; FLOWERS user's manual, 3rd edition, 1985