ADVANCED SEISMIC RETROFIT OF PUBLIC HOUSING PROJECT IN EILAT, ISRAEL

Y. Offir (1), A. Cohen (2), A. Shohat (3)

(1) Partner, Yaron Offir Engineers, yaron@yoe.co.il
(2) Engineer, Yaron Offir Engineers, avi@yoe.co.il
(3) Partner, Yaron Offir Engineers, alex@yoe.co.il

Abstract

The state of Israel Implemented a national building plan to promote the seismic retrofitting of private housing buildings, by providing financial benefits to owners. This program does not properly suit peripheral cities in Israel, where price of properties are lower, thus making the benefits unattractive. Unfortunately, these peripheral areas are also the ones with the highest seismic risk in the country, and are thus the buildings in largest need for retrofit. In order to try and correct this distortion, the Government decided to allocate State funds to retrofit public housing in peripheral cities, by promoting a pilot program to develop advanced seismic solutions within a very tight budget.

This paper presents the outcome of the pilot program, introducing its design and execution challenges. The pilot project was successfully executed by the National Housing Agency (Amidar) for 3 public housing blocks in the city of Eilat, which is situated in very close proximity to the African-Syrian fault line. The 4-story concrete dwellings examined were built in 1967, each containing 30 housing units. Some of them have an open-plan ground floor, while some of them have units on the ground floor. Design including a site-specific survey, structural lab testing, and foundation excavations. Design procedures were based on ASCE 41 for a design criteria of LS in the code based earthquake. Analyses of the structure included the use of nonlinear analyses for an ensemble of ground motions fitted to the site, as well as consideration of proximity to the active fault.

Due to the high seismic demand obtained in the lower period region of the design spectrum, as opposed to the relatively high natural period of the flexible structure, a design philosophy of preserving its natural behavior by not further stiffening, was chosen. Design efforts were focused on applying retrofit measures mostly to the ground floor, so as to minimize interruption to dwellers, who stayed put during the whole execution phase. Design principles were based on prevention of stiffening the structure, to prevent increase in loads, and alternatively making it more flexible by the cutting of walls on the ground floor, and the addition of energy dissipating elements (yielding steel braces, fabricated by a local welder), that are only activated at a certain displacement threshold. Brittle columns on the ground floor were strengthened using FRP sheets, and the truss-action created by this setting enabled solving the ground-surface fracture risk. Work also included retrofit of existing foundations, and treatment of old building infrastructure and material deterioration, as well as renewing facades and landscape development. Seismic retrofit costs were limited to approx. 8,000 USD per unit, which was less than 50% of the original conventional retrofit costs estimated (total retrofit costs including all developments were about 25,000 USD). Due to the successful outcome of the pilot project, MCH decided to broaden the project, and 4 additional dwellings are currently executed, with intentions of expanding the project to a national level.

Keywords: seismic retrofit, nonlinear analysis, public dwellings, damping.

1. Introduction

The Syrian-African fault line running along the Jordan Valley on the Israeli Eastern Border is the main source of tectonic activity in the State of Israel. The last reported strong earthquake of M6.3 occurred in 1927 around the Dead Sea region, and claimed hundreds of lives, mainly from populated cities such as Jerusalem and Nablus. This event followed the earthquake of 1836 which claimed over 20,000 lives from the cities of Tzfat and Tiberias and some cities of southern Lebanon. It has been estimated that a major earthquake is expected every 80 to 100 years, meaning that most Israelis today have never experienced such an earthquake in their homeland. This contributed to the lack of awareness about earthquake risks and hazards. The 1999 Izmit and Kocaeli earthquakes somewhat motivated national decision-makers to create a dedicated governmental commission to tackle seismic preparedness of the country. Significant steps towards this aim began in 2005, with the seismic retrofit of industrial structures with hazardous materials. Only in 2008 these efforts were extended to include various government agencies. One step was the implementation of a national building plan called “TAMA38” for retrofitting of private housing buildings, by providing financial benefits to owners (such as increased allowed building areas, tax exemptions, etc.) in order to carry out the seismic retrofit using private funds. This program does not properly suit peripheral cities in Israel, where price of properties are lower, making the benefits unattractive. Unfortunately, these peripheral areas are also the ones with the highest seismic risk along the fault, characterized by an old building stock, which was built quickly and with poor quality, to house immigrants during the previous century, and are thus the buildings in highest need for retrofit. In order to fix this distortion, the Government, via the Ministry of Construction and Housing (MCH) decided to allocate State funds to retrofit public housing in peripheral cities. Constraints and problems such as large building stock, disturbance to residents, and high costs of conventional retrofit that took place in some of the public housing neighborhoods in the last years obstructed progress. The MCH, therefore, decided to promote a pilot program, aimed at examining the use of advanced seismic solutions for retrofitting, at a pilot project for 3 public housing blocks in the city of Eilat, which is situated in very close proximity to the African-Syrian fault line. This paper presents the motivation for the pilot project, its outcome and success in comparison to projects carried out through conventional retrofit methods.

2. Seismic retrofit of public dwellings

2.1. The Israeli “Shikun”- public dwelling [1]

The first decades of the 20th century included several immigration waves to the land of the future State of Israel. These immigration movements led way to architects from European background (mainly Germany, Austria, France and England) to copy and locally implement European modern architecture of that period. The structural system of those buildings, who often had an open-plan ground floor with columns, are not preferable for seismic design, due to the weak/soft story which the column floor creates. While not an issue in the countries of origin, which are not located in areas of high seismicity, this deficiency was not known to local architects and engineers at the time, and thus was not taken into consideration.

In 1948, with the formation of the State of Israel, one of the main tasks of the young country was to create living and working places for its new and old immigrants. Within 3 years, the state’s population doubled from 700,000 in 1948 to 1,400,000 in 1951. Due to massive immigration extents, policies were implemented to provide immediate housing solutions, and single level temporary shacks were built. In 1952 as immigration rates reduced, the government strategically decided to house immigrants in peripheral regions of the country, utilizing cheap lands available in those areas. This policy intended to mitigate the problem of temporary housing, while develop cities in peripheral areas, thus spreading the population. Most housing project of those days were deliberately designed to be homogeneous, i.e. with equal unit sizes, and number of rooms (typically 2 rooms in earlier years and 3-4 rooms in later years). Within the next decade, approximately 20 new development cities were founded, on the basis of public housing. Due to sociological reasons, these development cities, to date, remain poor, with lack of compatible infrastructure, employment options, and industrial and commercial centers, compared to larger cities in the country. Some neighborhoods in these development cities are considered distressed neighborhoods, and are populated with low income population.

Nearly 50% of dwellings built in Israel until 1987 were built as public initiative, and were owned by the MCH, who, through government owned companies, were also in charge of upkeep and maintenance. Residents of these dwellings who were not permitted to privately repair their dwellings, along with a lack of government investment, led to the deterioration of the physical state of these buildings. In the late 1970s, a program to rehabilitate Shikun neighborhoods was initiated by the MCH, but this focused on physical repairs, and did not provide deep maintenance of structural elements. A parallel processes carried out from the legal perspective resulted in residents buying in on their units, and to date, only about 10% of dwellings are still publically owned by the State.

2.2. Seismic retrofit of public dwellings worldwide

Several countries worldwide have promoted programs to retrofit public dwellings to withstand earthquake loads. The State of California presented such guidelines in the 1980s-1990s [2, 3], and public buildings, as well as residential buildings, were retrofitted based on the Federal Act 101-614. New Zealand's Building Act from 2004 to reduce seismic damage [4] also deals with the matter. Major seismic retrofit measures have also been carried out in Japan and Turkey, countries with a high seismic hazard which have experienced major events in the last years. To the best of the authors' knowledge, the Israeli project is the first attempt to seismically retrofit public housing before a major seismic event, using solely direct government budget, without any tenants' founding. This case study, can, therefore, be used as a general work model for other countries.

2.3. Seismic retrofit of public dwellings in Israel

In early 2000s, actions to promote seismic preparedness had started at a State level, with government support to the various planning agencies. As part of this, a national plan known as "TAMA 38" was approved in 2008. The idea behind this plan was to fund structural retrofit measures against seismic hazards by utilizing incentives such as exemption from betterment taxes and allocation of larger building rights (including addition of rooms to existing apartments, and added floors/ new apartments). Due to the inflating local real estate market in the center of Israel, these incentives, which were originally supposed to serve an engineering target, took an entrepreneurship focus. In areas of high demand, building rights given out by the government as part of the TAMA 38 plan were exploited by contractors and entrepreneurs and investors, while neglecting the peripheral regions, with lower real-estate demand, making this plan financially unfeasible. Thus, in the areas most needed to undergo seismic retrofit due to larger seismic hazards, as well as being economically peripheral and poorer, this plan did not encourage actual seismic retrofit of buildings. To date, the state has invested over 4.5B dollars in rights handed out as part of the TAMA 38 plan, most of which have gone to areas which are not seismically at a high level or risk, while this money could have been invested in retrofitting buildings in areas of higher seismicity and population in need. At the end of 2019 the TAMA 38 plan was cancelled (by the year of 2021), but no alternative plan to promote holistic seismic retrofit of residential buildings has been presented by the government.

As of 2013, by the power of government decree 551, every public structure that is rehabilitated must also undergo seismic retrofit. The governmental housing company, Amidar, with the support of the MCH has carried out the retrofit of 28 buildings in peripheral cities in Israel in the years 2013-2015 [5]. Retrofit was carried out using conventional strengthening methods, including the use of added shear walls in building perimeters. As these solutions did not include treatment of the existing structural system, their effectiveness is questioned, since the existing structural system lacks appropriate reinforcement detailing, and is often in an advanced deteriorated condition. These buildings are expected to behave in a brittle manner when a seismic event will occur, and only the new added walls and the existing parts which are in close vicinity to these walls are likely to remain standing following such an event. In addition, the abovementioned projects were hard to execute, as the addition of concrete shear walls meant interrupting daily life in order to allow strengthening, which raised the objection of residents who feared temporary evacuation. These solutions were also found to be costly and lengthy, and demanded treatment of infrastructure that was disrupted due to digging foundations for new concrete walls, in addition to increasing demands by residents to improve appearance of facades and surrounding development. In 2016 the MCH initiated a pilot project to examine an alternative through the use of advanced seismic solutions for structural retrofit of public dwellings, in order to compare solutions and execution feasibility to the use over conventional methods. This paper focuses on the outcome of this pilot project.

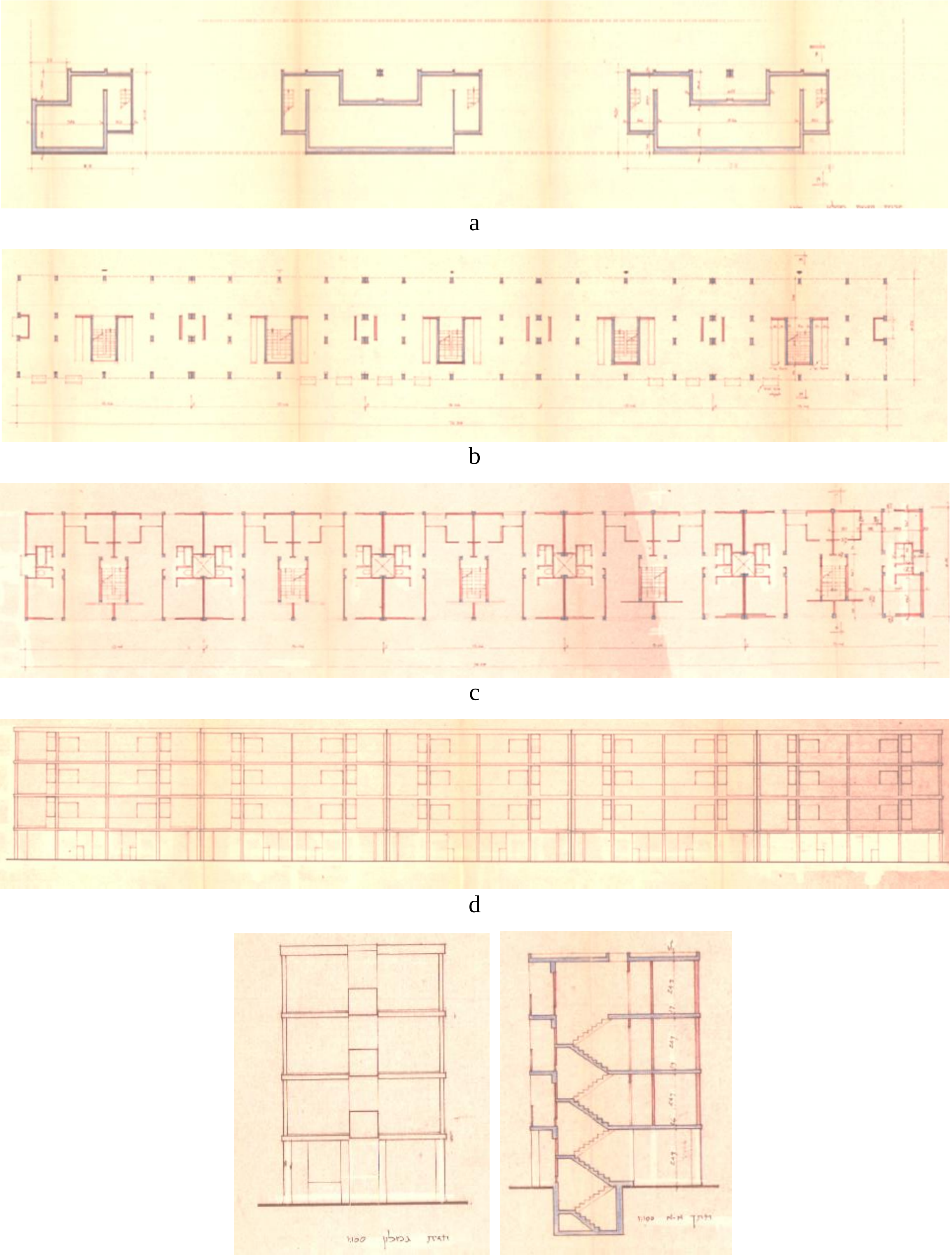
3. Pilot project: structure description and assessment of existing seismic behavior

Pilot project defined by Amidar included three old "Train"-type reinforced concrete (RC) buildings (see Fig. 1) built in 1967 in the city of Eilat, each containing 30 apartment units, raising 3 stories over an underground floor. The ground on which these buildings are located is slightly sloped to the east. Each building is comprised of 5 sub-buildings separated by an expansion joint. Each sub-building contains 6 apartments over 3 floors, on top of an open column floor and a basement housing shelters. Each sub-building is 15m long, 8.2m wide, 10.5m high above ground. See building plans in Fig. 2. The structural system of the buildings is RC frames with masonry infills and waffle slabs. No infills are present at the ground level, creating a soft-story configuration prone to failure. Column cross-sections are 20x40cm at the ground level and 20x25cm^2 at stories above, with center-to-center spans varying between 2.74 to 4.25m. Perimeter beams are present in both directions, with cross-sections ranging between 27x36cm^2 and 13x45cm^2. Waffle slabs consist of 12-14cm ribs with a 5cm toping, spanning in the north-to-south direction. Infill panels consist of unreinforced hollow-core concrete blocks. In the front facade (Fig. 2d), infill panels present vertical openings, which do not allow the formation of a diagonal compression strut since this requires the lateral support of the column. In the lateral perimeter frames, full infill panels are present, which were taken into account in the numerical model.

The foundation consist of 1.30m square footings supporting 40x25cm base columns rising between 1.80 and 3.0 m. On-site material testing revealed concrete strengths ranging from 21to 40 MPa. The rebar configuration of the 20x40cm columns were 8x12mm longitudinal bars with 6mm stirrups with a strength of 220 Mpa and ε=0.20 as rapture strain.

Fig. 1- "Train"-type building before retrofit

The site for the selected the pilot project is located in the city of Eilat in the southern part of the State of Israel. Eilat is situated on the Arava fault, which is part of the Deas Sea Transform (DST) between the Arabian and Sinai tectonic plates. The tectonic system is of a "pull apart" type between 3 basins crates by strike-slip transforms (see Figs. 3-4). Not much information is known regarding their behavior. For the project, a probabilistic site hazard assessment (PSHA) was carried out **[6]** so as to produce expected vibrations at the specific site (see Fig. 5). Surface faulting was also found to be a potential hazard for the specific site. To account for soil-structure interaction, 8 borehole tests were carried out in the soil, which revealed a one meter deep filling layer and 8 meters of granular tin sand. The two top layers are of high density with SPT>50. As part of site development, retaining walls were executed to create a flat surface at ground level.



a

b

c

d

(e)

Fig. 2- original building plans: (a) underground level, (b) open column floor, (c) typical floor, (d) frontal façade, and (e) section cut and side façade

The design performance criteria for seismic hazard was defined as Life Safety (LS) for a 10% probability of exceedance in 50 years (475 year return period).

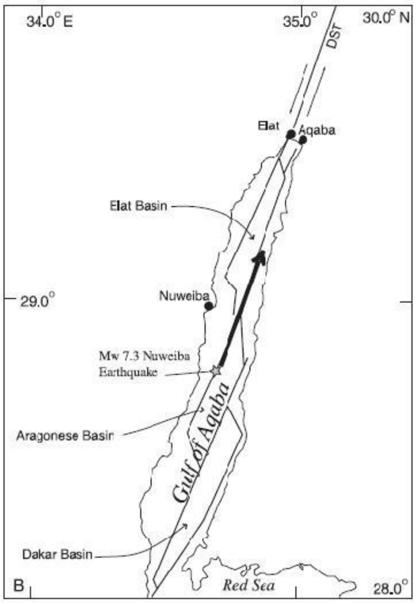


Fig. 3- Map of basins and DST in the Eilat area, marking the 1995 earthquake epicenter 70km south-west of Eilat (adapted from [6])

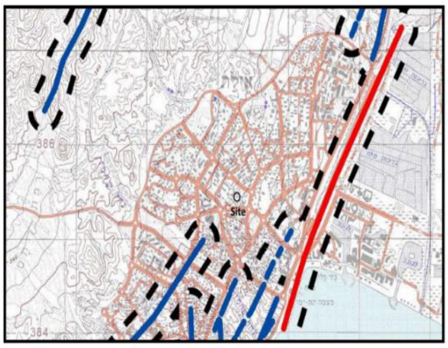


Fig. 4- location of site marked on local active fault map (adapted from Geological Survey of Israel map)

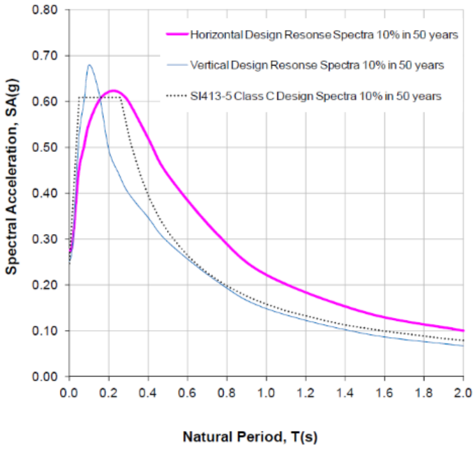


Fig. 5- horizontal and vertical design spectra for 10% in 50yrs ground motion, soil type C. (adapted from [6])

Analytic assessment was carried out according to principles of ASCE 41[7] using SAP 2000 finite elements software. Element stiffness's were reduced so as to account for cracking of the concrete during a seismic event. The analysis included modal, nonlinear pushover and nonlinear time-history analyses. In Fig. 6 results obtained from pushover analysis in the short (transverse) direction of the structure can be seen. Capacity was found to be lower in this direction than in the long direction due to column orientation. The formation of the failure mechanism in different elements can be seen in Fig. 6. The limit states at plastic hinges formed at the performance point for a representative sub-building can be seen in Fig. 7. As can be observed, most of the hinging occurs at the ground weak/soft story. Columns first yield in bending at small displacements and then fail in shear in larger displacements, due to poor detailing of shear reinforcement. First story infill walls are cracked at this point, but do not present a threat to overall floor integrity.

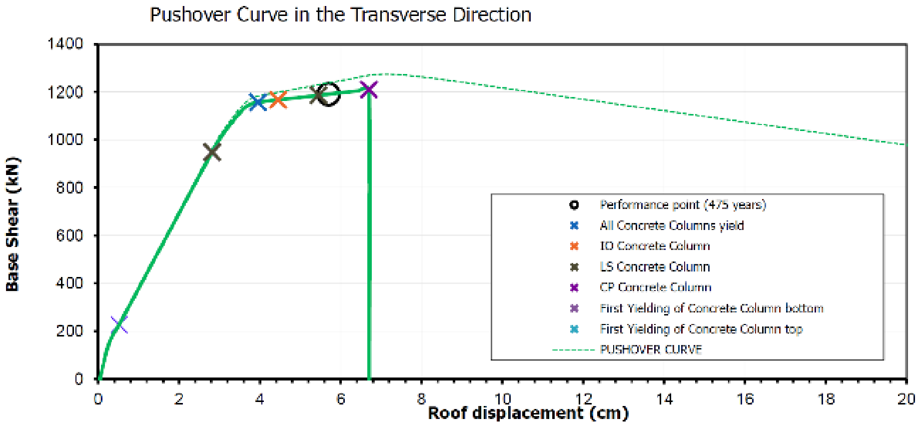


Fig. 6- Pushover capacity curve obtained from analysis, short (transverse) direction

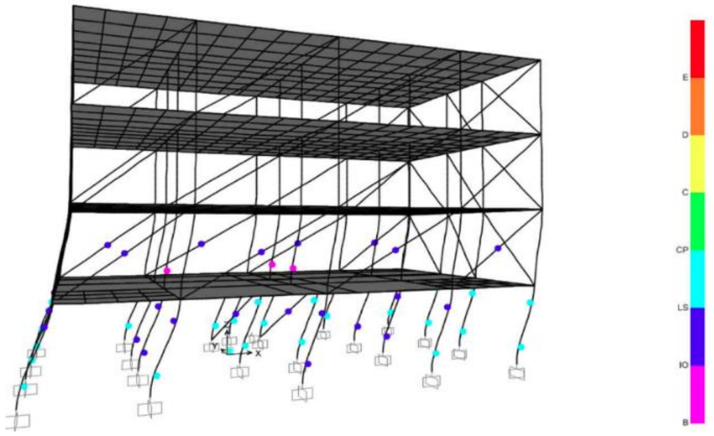


Fig. -7 Plastic hinge limit states at performance point for seismic hazard of 10% in 50 yrs.

4. Retrofit design

Retrofit design was carried out after thorough site investigations including PSHA [6], laboratory testing [8], and excavation of foundations [9]. As acceleration demands were found to be high at high frequency ranges (see Fig. 5 and 8), retrofit design philosophy focused on structural weakening in order to allow period-shifting to lower frequency (larger period) areas of the design spectrum (see Fig. 8) so as to increase the ductility. The retrofit scheme (Fig. 9) included:

- Foundation rehabilitation including a perimeter grade beam, and strengthening at locations where steel braces are added.
- Weakening of walls in staircase areas by vertical section cuts on ground floor level.
- Separation of staircase landing areas from stairs so as to eliminate stiffening truss crated by their connection.
- Use of FRP sheets to wrap columns on ground floor (see Fig. 9) so as to increase their ductility and allow a larger inter-story drift before failure.
- Energy dissipation through yielding steel braces (locally manufactured). These braces are activated after a 1.5cm displacement is developed (in positive and negative directions), which allows for free movement of the un-stiffened structure up to a certain limit. After the gap is closed, two braces in each direction buckle, while two others yield in tension (see Fig. 9). The damping produced by this mechanism was computed as 17.5% equivalent viscous damping.

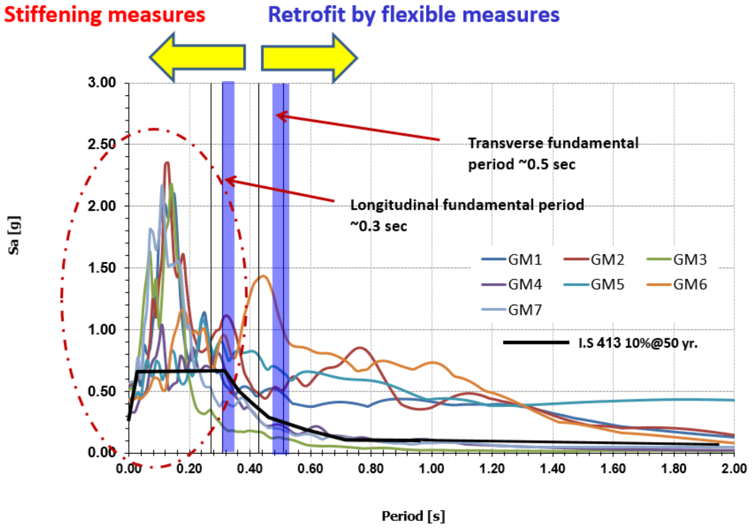


Fig. 8- Retrofit principle by weakening of structure rather than stiffening to larger acceleration areas at higher frequencies

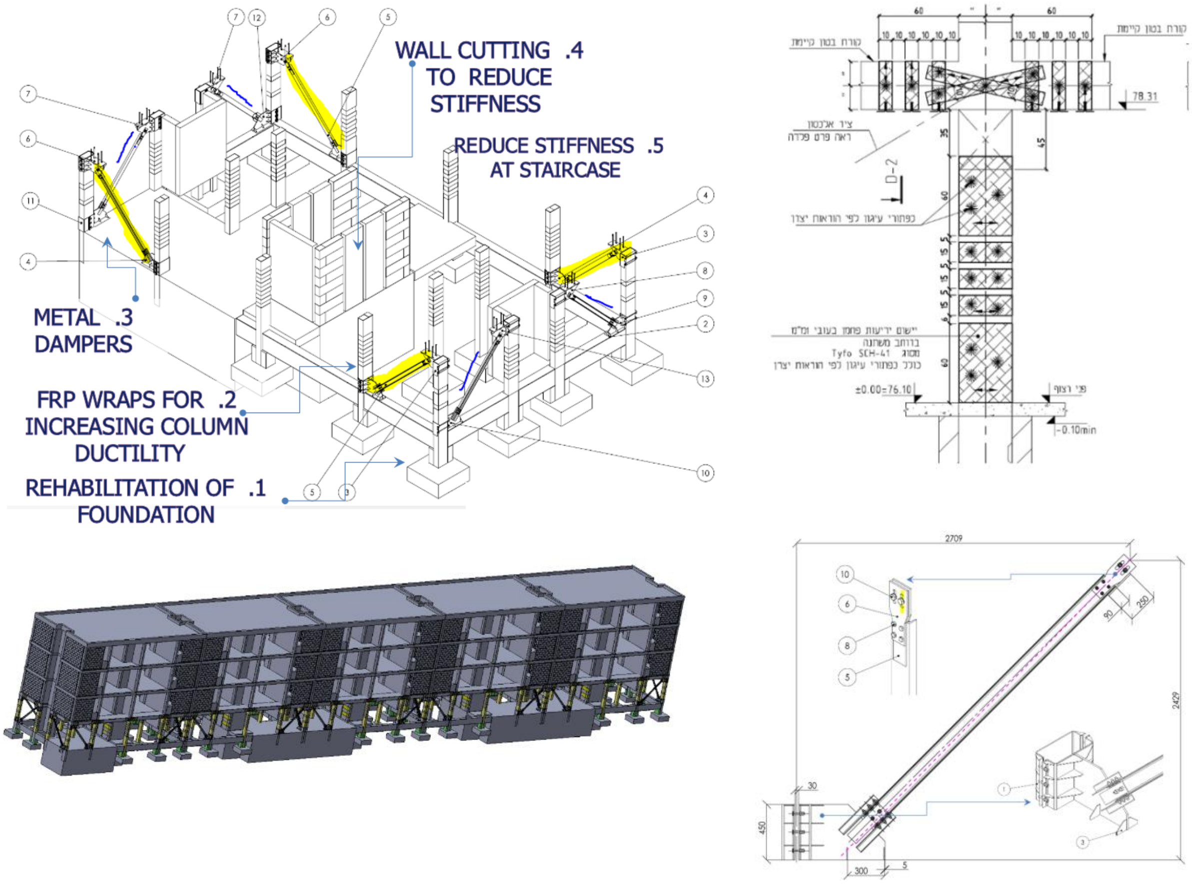


Fig. 9- Retrofit measures, clockwise from top left: Retrofit scheme sketch, FRP jacketing of concrete columns, isometric view of 3D model, and steel brace details.

Nonlinear pushover analysis was performed for the retrofitted structure, and a more ductile behavior was obtained. The performance point was reached before failure of any of the main structural elements. Nonlinear time history analyses carried out for the retrofitted structure showed a reduction of up to 45% in forces (see Fig. 10).

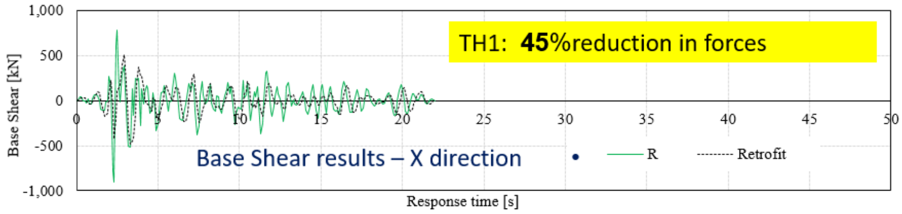


Fig. 10- Nonlinear time history analysis comparison of base shear of existing and retrofitted structure

5. Discussion on the use of advanced in comparison to conventional retrofit solutions

Prior to the implementation of the pilot project described herein, between the years 2012-2015, the MCH initiated the seismic retrofit of 28 buildings in development cities in Israel using conventional retrofit solutions (through the addition of RC shear walls). These solutions are used for comparison with the use of advanced design solution in the project described herein. Table 1 compares the use of conventional and advanced solutions for this project.

Table 1- Comparison between retrofit using conventional or advanced methods for project pilot

Parameter	Conventional solution	Advanced solution
Execution time	12-18 months	6-12 month **(30%50-% faster)**
Design requirements		A more in-depth investigation of existing structure including foundation excavation, structural lab testing, site specific survey, soil structure interaction parameters. **More reliable, but requires additional design time.**
Separation of structural and finishing works	Must finish structural works before finishes due to major use of concrete	No need to postpone finishing works except for on ground level, **most works can be carried out in parallel.**
Costs reduction due to mass redundancy	30% or more expected	30% or more expected
Construction costs		**40-50% savings**
Work input		**Smaller amount of workers due to leaner construction works**
Disturbance to residents	Must be evacuated for part of the execution period.	**No evacuation of residents**
Other considerations	Less need for architectural finishes	Less need for foundation strengthening

Execution times for the construction of retrofit works were 12 months for the first pilot building, 9 months for the second pilot building, and about 6 months for the next 3 building which are under construction now. The third pilot building was execute in 12 months due to a different geometry which required design modifications. Success of the pilot project was mainly due to:

Concentration of retrofit measures in a single (ground) level which meant minimal disruptions to daily life of residents, who were allowed to continue occupying their apartment units throughout all construction stages, and no evacuation was needed.

Retrofit costs (for structural works) were around 8,000 USD (including VAT) per unit, which was less than 50% of the estimate for construction using conventional methods. Together, along with rehabilitation, site development, upgrade of infrastructure and façade treatment; the cost per unit was approximately 25,000 USD. These costs account for an extra 20% freight fee in material and construction work costs due to Eilat's remote location. These costs are expected to be lower in central cities. Pictures from execution stages can be found in Fig. 11, and the final appearance of the retrofitted structure can be found in Fig. 12.

Fig. 11- Construction execution, clockwise from top left: RC column FRP jacketing, foundation retrofit, and steel brace details.

Fig. 12- Final appearance of structure after completion of retrofit

6. Conclusions

Three old “Train”-type RC public dwellings buildings were seismically retrofit such a manner as to avoid stiffening the structure, in order take advantage of the low fundamental frequencies and significantly reduced the response in an earthquake event. This is achieved by increasing the ductility of the existing columns and introducing simple energy dissipating steel diagonal details as described above. While this structural-weakening technic is not new, its design and implementation are. The design team successfully managed to provide a solution to seismically retrofit these occupied structures without the need to evacuate any tenant. Moreover, due to a very tight budget, the reinforcements were narrowed to the minimum required to achieve the desired performance, achieving a high degree of efficiency.

The advance solution took place in this pilot project show substantial benefits compared to conventional solutions such as the use of new concrete shear walls. Execution times for the construction of retrofit works were reduced to a third, from 18 months to about 6 months. The concentration of the retrofit measures to a single (ground) level allowed to minimize any disruptions to the daily life of residents. Furthermore retrofit costs were reduce by more than 50 percent.

Due to the success of the pilot project, the MCH decided to expand the project to a national level and implement advanced design solutions in future retrofit projects. This project not only highlights the engineering solutions, but a success in policy implementation that facilitated the retrofit and a structure with a higher seismic performance level, that otherwise would not have been achieved. The real success is the effective collaboration between the government, contractors, the private sector and the engineering team, that can lead to a national wide retrofit project.

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