Comparison between Static and Dynamic Seismic Performance Analysis of Reinforced Concrete Structure through a Case Study of "Seaside Hotel"

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Abstract**—** In this research presents a case study of a RC Building constructed in 1970 namely the Seaside Hotel, a 10 storey building in Famagusta, North Cyprus. This study consists of three stages: data collection (building plans, material properties, structural condition and reinforcement details) using destructive and non-destructive tests; software modeling of the structure using SAP2000, non-linear static pushover analysis and non-linear dynamic time history analysis for seismic performance assessment based on FEMA 440 and TEC2007 codes and comparison of both analysis methods are conducted .

Keywords- RC Multistory building; Seismic performance assessment; Earthquake resistance; Pushover Analysis and Nonlinear time-history analysis.

I. INTRODUCTION

In recent years great developments have been made in the assessment of existing buildings and their performance in resistance to earthquake loading, potential seismic risk, vulnerability and lateral loads. Existing buildings can be repaired and strengthened to include new developments and methods to resist earthquake and seismic loads, which is the most economical way to safeguard against the economic and social catastrophe affected by severe seismic activity in urban environments. Traditional buildings in the 20th century were mostly constructed without sufficient protection, considering only the gravity loads of the structure [3]. On the other hand, steel bars in the concrete may also corrode depending on construction age and environmental factors and effect structure performance against earthquakes [1].

II. RESEARCH SIGNIFICANCE

Performance based-seismic design has become an important tool for earthquake resistant design. In addition, performance and assessment are required for existing buildings whereby only gravity load was considered during design, neglecting lateral and seismic load as a whole. Performance assessment of existing buildings should be carried out by considering FEMA [3]. When all the required properties of the building and its level of damage are determined, the performance assessment analysis can be undertaken. Subsequently, the suitable performance method must be chosen for a particular building and repair methods can be chosen contemporaneously with the rehabilitation of the structure.

III. EXPERIMENTAL METHODOLOGY AND DATA COLLECTION

A. Purposes of research

The main aim of this study is to determine the behavior of a building during an earthquake and its contributing to the building system before strengthening. The collection of data for assessment and evaluation the performance of the building is essential to the nature of this study. In TEC 2007 "Turkish Standard Earthquake Code'' [10], includes several important points before an assessment of an existing building as collection data can proceed;

1. Determination of information level (limited, moderate or comprehensive).
2. Determination of concrete properties and reinforcing bars.
3. Calculation of elements critical cross-section strengths (bending and shear).
4. Determination of size, location and number of reinforcing bars in sections.
5. Determination of failure types of reinforced concrete elements.
6. Determination of bending and wrapping reinforcement amounts and their details which are required for the determination of element's damage limits.

B. Case Study Data

This study is a case study of strengthening and assessment performance of an existing building.

Building Name: Seaside Hotel.

Location: Located alongside the Salamis Bay Continental Hotel and Resort on the main Salamis Road, Famagusta,TRNC shown in Fig. 1.

Site Coordinates: 35°12'19.67" N 33°54'06.23" E " Google Earth".

Construction History: Constructed in the early 1970s.
Structural Type: Reinforced concrete building and consists of 10 storeys.
Plan Description: Comprised of two parts: the main section of the hotel and the hotel reception area. The building area dimensions are 24.7 m x 8.80 m and the height of each floor is 3 m.

Figure 1. Seaside Hotel in Famagusta, Cyprus.

C. *Destructive Tests*

1) *Concrete Material Characteristics*

According to ASTM C42 / C42M - 13 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete. Fifty six samples were taken from the building as mentioned [TEC 2007] and in order to obtain the variability of concrete strength behavior of structure minimum numbers of core samples to be taken are fifty six by having at least three samples from each floor in high rehabilitation performance and the results obtained as shown in Table I.

TABLE I - COMPRESSIVE STRENGTH TEST RESULTS FOR EACH FLOOR.

No.	Floor Number	Columns Compressive strength(MPa)	Beams Compressive strength(MPa)
1	(Ground)	14	36
2	1st floor	14	36
3	2nd floor	33	7
4	3rd floor	8	34
5	4th floor	11	21
6	5th floor	12	25
7	6th floor	8	12
8	7th floor	12	28
9	8th floor	12	20
10	9th floor	11	33

2) *Reinforced Steel bar Material Characteristics*

According to ASTM E8 referenced in this study, a tension test (tensile strength test) was made for 3 specimens of steel bars having (diameter #10). General specifications of steel bars depend on the diameter of the steel bar used for testing and the specimen length should be equal to 20 times the diameter it means the length of the bar is (20 cm) as shown in Fig. 2 and clarify results in Table II.

TABLE II – TENSILE STRENGTH TEST CALCULATIONS.

No.	Yield (kN)	Ult.(kN)	Elongation(mm)	Area of bar(10mm)	Yield Strength (MPa)	Ult.Strength (MPa)	Strain (%)
1	17.5	22.9	114	78.5	222.93	291.72	14
2	18.2	24.4	114	78.5	231.85	310.83	14
3	17.5	24.1	113	78.5	222.93	307.01	12

Figure 2. Three steel bar specimen before and after tension test.

D. *Non-Destructive Tests*

1) *Reinforcement Details Characteristics*

Characteristics with reinforcement details for sections of columns and beams for frame structural members determined via Ferro scan device shown in Fig.3 Reinforcement details are shown in Table III and Table IV.

TABLE III - BEAMS SECTION CHARACTERIZATIONS.

Sections	Dim. (cm)	Top bars	Bent-up bars	Bottom bars	Add. at Bottom bars	Stirrup bars
Beam	40x60	2 Φ16	2Φ16	2 Φ16	2 Φ 16	Φ10/15

TABLE IV– COLUMNS SECTION CHARACTERIZATIONS.

Sections	Dim.(cm)	Major	Minor	Middle layer 1	Middle layer 2	Stirrup
Column C1	65x100	4 Φ 20	3Φ20	2 Φ16	---------	Φ10/15
Column C2	80x65	3 Φ 20	3 Φ20	2 Φ16	---------	Φ10/15
Column C3	65x45	3 Φ 20	3 Φ20	2 Φ16	---------	Φ10/15
Column C4	35x65	2 Φ20	2 Φ20	2 Φ16	---------	Φ10/15
Column C5	45x65	2 Φ 20	2 Φ20	2 Φ16	---------	Φ10/15
Column C6	85x45	3 Φ 20	3 Φ20	2 Φ16	---------	Φ10/15
Column C7	50x35	2 Φ20	2 Φ20	2 Φ16	---------	Φ10/15
Column C8	35x50	2 Φ20	2 Φ20	2 Φ16	---------	Φ10/15

Figure 3. Ferro scan device and Reinforcement details scanning.

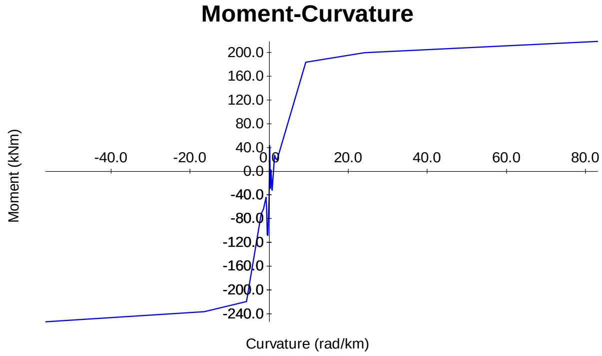
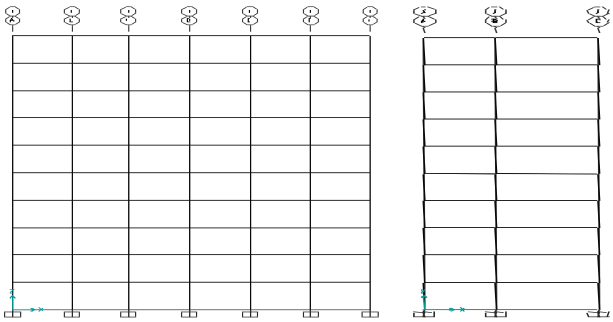


Figure 5. Column Moment-curvature relationship.

IV. SEISMIC PERFORMANCE ANALYSIS

2D seismic analysis of two frames from a case study will be used; the Seaside hotel RC existing building by each direction which is X-Direction and Y-Direction as shown in Fig.4. The additional load for all members was identified 1.5 kN/m^2 with the gravity direction, 3.5 kN/m^2 was identified as live load in the direction of gravity. The self-weight of slabs was found for 20cm thickness as 5.0 kN/m^2 distributed in the gravity direction, 3 kN/m^2 was defined as the wall load for one meter square distributed along the beams over the direction of gravity. After determining the gravity loads such as dead loads and live loads, all element details were identified to calculate the total axial load of both frames provided by Sap2000.



X-Direction frame Y-Direct frame

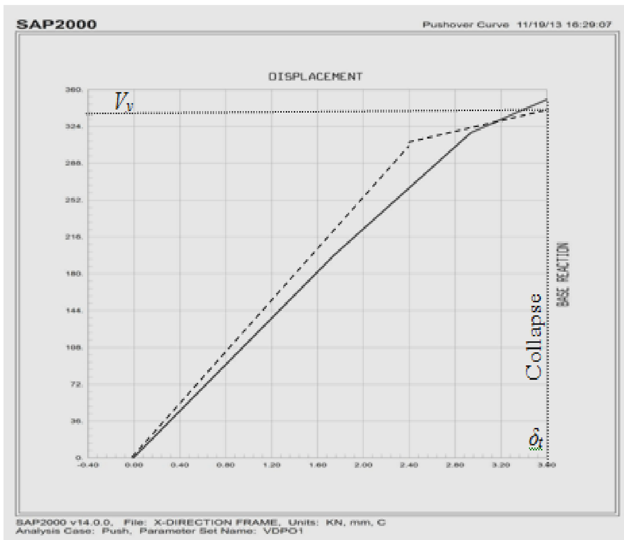
Figure 4. Two dimensional frames model from both directions (Sea Side Hotel).

1) Sectional Analysis of Reinforced Concrete Members

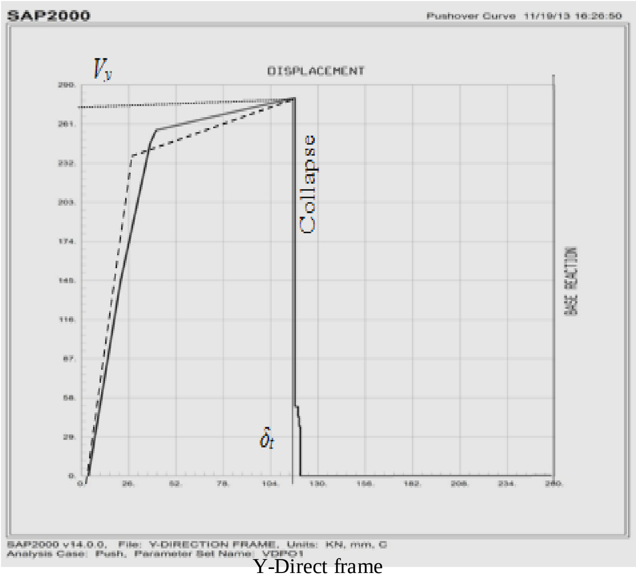
Is the approach taken to calculate the strength and deformation characteristics through moment-curvature relation for reinforced concrete members. In this study, software such as the "Response-2000" program was used, shown in Fig. 5.

2) Non-Linear Static Pushover Analysis Method

A static pushover analysis is one method of assessing the seismic demand of an existing building. It represents a static approximation of the structure response under dynamic loads such as earthquake loading by applying a vertical distribution of monotonically increasing lateral loads to a model which appropriates the material non-linearity of the structure. Target displacement relation with base shear force are calculated according to FEMA440 procedure described in "ASCE, 2000".Capacity curve (Pushover Curve) for x direction frame model of the building where target displacement is calculated as δ_t = 10.20 mm and base shear force causing this displacement is equal to 300 kN, the capacity curve yielding will start when roof is displaced 2.00 mm and its first collapse occurs at 12 mm. Capacity curve (Pushover Curve) for y-direction frame model of the building where target displacement is calculated as δ_t = 108.20 mm and base shear force causing this displacement is equal to 285 kN, the capacity curve yielding will start when roof is displaced 26.00 mm, and its first collapse occurs at 120 to 125 mm. At this point the building cannot resist any more loading and will be in mechanism. As Shown in Fig. 6, Fig.7 and Fig. 8.



X-Direction frame



Y-Direct frame

Figure 6. Pushover curve of both frame.

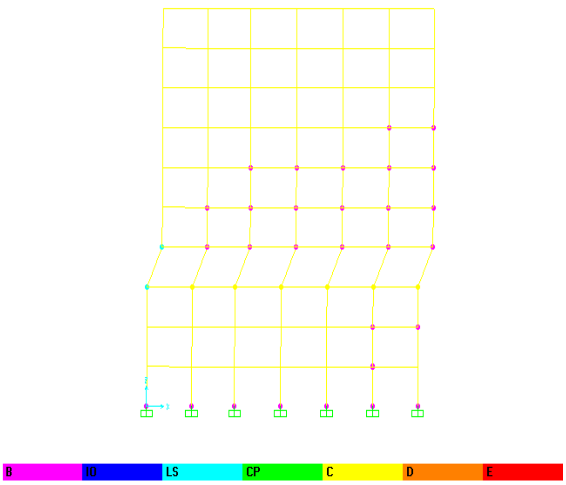


Figure 7. Plastic hinge of (X-direction) frame.

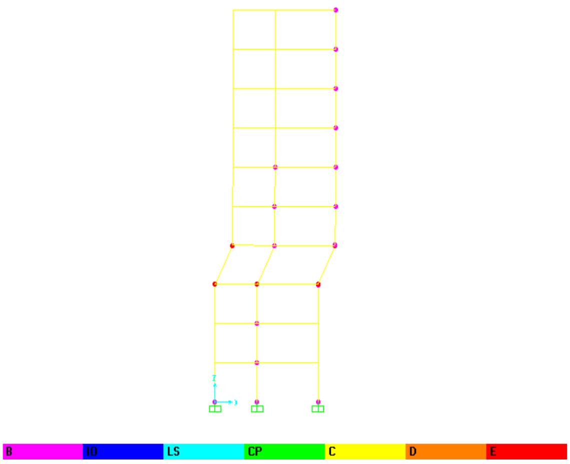


Figure 8. Plastic hinge of (Y-direction) frame.

3) *Non-Linear Dynamic Time History Analysis Method*

The maximum displacement due to applied time history records for frame model x-direction is shown in Table V and Table VI. This shows the behavior of control nodes in term of (S_a-S_d) relationship where the structure is responding elastically to the applied time series for both sides X and Y directions also Probability curve was drawn by log-normal distribution statistics method as shown in Fig.9 and Fig.10.

TABLE V – SPECTRAL DISPLACEMENT & SPECTRAL ACCELERATION (X-DIRECTION FRAME).

GM	S_a(g)	S_d (mm)
TH1	0.05	6.68
TH2	0.03	4.01
TH3	0.03	4.57
TH4	0.04	5.32
TH5	0.05	6.53
TH6	0.03	3.51
TH7	0.07	9.58
TH8	0.05	7.18
TH9	0.04	5.64
TH10	0.06	8.39
TH11	0.04	5.46
TH12	0.02	3.20
TH13	0.07	9.38
TH14	0.07	9.90
TH15	0.03	4.68
TH16	0.02	3.15
TH17	0.03	4.48
TH18	0.05	6.66
TH19	0.04	5.15
TH20	0.04	5.68
	Mean (S_d)	6.20
	Standard Deviation(SD)	2.20
	Mean (S_d) ± SD	(8.41, 3.99)

TABLE VI – SPECTRAL DISPLACEMENT & SPECTRAL ACCELERATION (Y-DIRECTION FRAME).

GM	S_a(g)	S_d (mm)
TH1	0.07	22.40
TH2	0.51	71.20
TH3	0.72	100.01
TH4	0.73	101.20
TH5	0.48	66.90
TH6	0.47	65.99

TH7	0.30	41.15
TH8	0.52	72.98
TH9	0.17	24.20
TH10	0.26	36.00
TH11	0.40	55.35
TH12	0.53	74.34
TH13	0.12	16.33
TH14	0.08	11.30
TH15	1.44	201.01
TH16	0.10	14.13
TH17	0.56	78.19
TH18	0.05	7.15
TH19	0.15	21.3
TH20	0.17	24.13
	Mean (S_d)	55.26
	Standard Deviation(SD)	45.45
	Mean (S_d) ± SD	(100.71, 9.80)

The above table is continuation of Table VI.

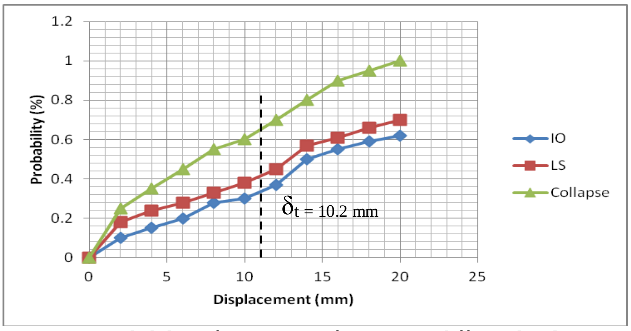


Figure 9. Probability of structure performance in different levels -(X-Direction).

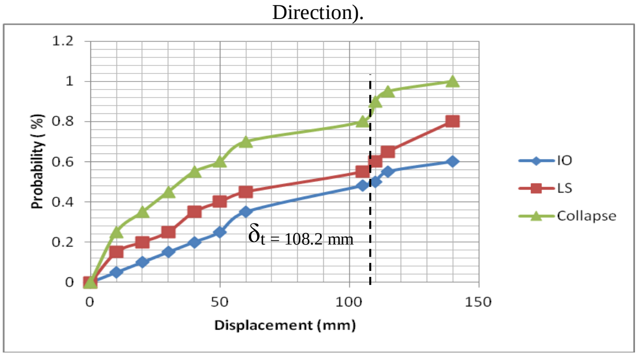


Figure 10. Probability of structure performance in different levels -(Y-Direction).

V. Comparison of Seismic Analysis Methods

By comparing the damage level obtained with the damage predicted using both the Non-linear static pushover analysis and Non-linear time history dynamic analysis methods, both procedures were found to the same level of performance. The actual damage level, acceptance limits and instability of both methodologies can be showing in Table VII.

TABLE VII– COMAPRISION BETWWEN METHODS OF SEISMIC PERFORMANCES OF BUILDING.

Structure Frame direction	**Pushover Analysis**		**Time history analysis**	
	δ_t* *(FEMA440)	***DG(Lang)***	***Accepted***	***Unstable***
X-direction	CP	4	40%	60%
Y-direction	CP	4	30%	70%

VI. CONCLUSIONS

Based on the results of the seismic analysis results, the following conclusions are drawn:

1. One of the most common modes of failure of a structure is the defeat of stability.
2. The existing structure was in collapse level (C)
3. Although the average compressive strength of the concrete of the existing structure was obtained between range (7-36) MPa.
4. Tensile strength of steel reinforcement bars is 220 MPa as standard.
5. Two different alternative procedures were introduced, namely non-linear static and non-linear dynamic assessment procedures. In this study the performance of both procedures are examined. Both procedures were found to the same level of performance as showing in Table VII.

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