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ANALYSIS OF EXTERIOR BEAM-COLUMN CONNECTION ON STRUCTURES OF MARRAKECH SUITES APARTMENT BY USING ABAQUS CAE V6.14 PROGRAM ON THE EARTHQUAKE AREA 4

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Abstract*: *The structure of the building planning reinforced concrete building with confined masonry, to the area of beam-column connection is critical area that will need to be design specifically that can be deforming when earthquake occurs it can ductile deformation. The stress-strain relationships of concrete needs to be known in order to obtain a description of the strain stress produced. Research of beam-column joint modeled by using the CDP feature of ABAQUS CAE v6.14 to define the ductile behavior of concrete. Beam-column joint reviewed is an exterior joint with dimensions of beam B14-25 500 x 900 mm, length 3500 mm, beam B16-25 600 x 600 mm, length 6600 mm, column dimensions 600 x 1100 mm, and the total height is 6600 mm. Period boundaries are qualifyed (6,29 second > 5,628 second), conditions of displacement are qualifyed (13,2 cm>6,93 cm), so the structure is resistant to earthquakes. Ductility (μ) values is 5,26, and included in partial ductility (μ= 1,0-5,29). Differences in values on the theoretical strain (Park and Paulay) and numerical strain (ABAQUS CAE v6.14) is 13,91% greater numerical strain than theoretical strain.

***Keywords* –** Earthquake, Joint, Stress, Strain, ABAQUS

I. INTRODUCTION THEORETICAL BACKGROUND

Planning of the concrete reinforced building structure earthquake resistant, in the area of the beam-column connection which is a critical area that needs to be designed specifically so that when the earthquake happens, it can be deforming in ductile. On the beam-column connection, the transfer of the beam load to the column will happen and it will continue to be transferred to the foundation. Thus, the connection of beam-column must be ascertained to be able to bear the burden which appear so that the load transfer process can happen perfectly.

To get the building structures that are safe and resistant to earthquakes, structures must be designed abide by earthquake resistant construction. Planning structures of Marrakech Suites Apartments are re-analyzed using the method of Sistem Rangka Pemikul Momen Khusus (SRPMK) which is designed using the concept of strong column weak beam (strong beam, weak column) in accordance with the principles of earthquake resistant building. The process of analysis of the structure of the building was made by using ETABS v16.0.3 and ABAQUS CAE v6.14 programs.

The research aims to find out the aspects of planning of building, analyzing earthquake loads using Static Equivalent Analysis, Spectrum Response Dynamic and Time History and analyze the performance of the building as well as the relationship of stress-strain especially on the beam-column connection.

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II. METHODOLOGY

The planning stages of 37-floor Apartment Marrakech Suites as follows:

1. Data collection in the form of N-SPT, design criteria, determination of the level of earthquake sites, data input parameter and loading.
2. Structure modeling in ETABS v16.0.3 program.
3. Analysis of earthquake.
4. Analysis of the output of ETABS v16.0.3 and choosing the beam-column review.
5. Calculation of reinforcement of beam-column review by using Mathcad v14.

Analysis of stress and strain of beam-column connection using ABAQUS CAE v6.14 and compared with Park Paulay.

III. DESIGN OF THE STRUCTURE

1. Determine the category of the structural risk of building and primary factors Based on SNI of Earthquake 03-1726-2002 section 4.1.2. it is mentioned that apartment building has primary factors (Ie) = 1.0.
2. Specifies the level of the site

Seismic design criteria in the planning of a building on the ground surface or the determination of the magnitude amplification of the earthquake peak acceleration of bedrock to ground level for a given site, then that site should be clarified in advance. The soil profile should be classified first, referring to the SNI of Earthquake 03-1726-2002 section 4.6.3. The determination of the level of the site should be in accordance with the investigation results of the soil in the field. Soil data results based on the value of SPT (Soil Penetration Test) is calculated by the formula:

$$\bar{N} = \frac{\sum_{i=1}^{n} ti}{\sum_{i=1}^{n} \frac{ti}{Ni}}$$

TABLE I
N-SPT VALUE

Layer to-i	Depth (m)	Thick Layer (d) (m)	N-SPT Value	d/ N-SPT
1	3	3	28	0.11
2	6	3	50	0.06
3	9	3	26	0.12
4	12	3	50	0.06
5	15	3	50	0.06
6	17	3	50	0.06
7	21	3	50	0.06
8	24	3	50	0.06
9	27	3	50	0.06
10	30	3	47	0.06
TOTAL		30		0.71

Because N ≤ 15 < 50, then it belongs to the medium soil

3. Design of response spectrum for medium soil are as follows

TABLE 2
THE VALUE OF DESIGN OF RESPONSE SPECTRUM

PGA (g)	0,357
SS (g)	0,683
S1 (g)	0,297
CRS	0,999
CR1	0,939
FPGA	1,143
FA	1,254
FV	1,807
PSA (g)	0,408
SMS (g)	0,856
SM1 (g)	0,536
SDS (g)	0,571
SD1 (g)	0,357
T0 (sec)	0,125
TS (sec)	0,626

4. Determining factors of earthquake reduction Based on SNI of earthquake 03-1726-2002 section 4.3.3. the value of the factor of earthquake reduction (R) is 8.5.

5. Structure of the period (T) analysis of vibrating time of ETABS v16.0.3 for Mode 1 (Tcy) and Mode 2 (Tcx) is: The vibrating time of Mode 1 Structure (Y direction) with T_{cy} = 5.628 seconds and the vibrating time of Mode 2 Structure (Y direction) with T_{cx} = 5.336 seconds.
 In SNI of earthquake of 03-1726-2002 section 5.6 coefficients □ for the earthquake zone 4 is 0.17. Then,
 Tcx < □□x n
 5,336 < 0,17 x 37
 5,336 < 6,29 → **OK**
 Tcy < □□x n
 5,628 < 0,17 x 37
 5,628 < 6,29 → **OK**
 The vibrating time of building structure meets the requirements. The building has sufficient rigidity.

6. Base shear coefficient of earthquake
 Because of the vibrating time on the structure for the X and Y directions are different, then the factor values of earthquake response are also different. Value plan of earthquake spectrum can be calculated:
 Earthquake static X direction (Mode 2),
 T1 = 5,336 seconds – C_1 = 0,42/5,336 = 0,078
 Earthquake static Y direction (Mode 1),
 T2 = 5,628 seconds – C_2 = 0,42/5,628 = 0,074
 The magnitude of the earthquake shear coefficient for X and Y direction can be calculated as follows:
 Earthquake base shear coefficient of X direction = (C_1 x I)/R = (0,078x1)/8,5 = 0,009
 Earthquake base shear coefficient of Y direction = (C_2 x I)/R = (0,074x1)/8,5 = 0,008

7. Determination of eccentricity plan
 SNI of earthquake 03-1726-2002 section 5.4.3 mentioned that for 0 < e ≤ 0,3b , then ed = 1,5e + 0,05 or ed = e – 0,05b
 From the results of calculation of eccentricity plan (ed) the most influential = 1,5e + 0,05b.

8. Calculation of the weight of the building (Wt)
 The weight of the structure that is used in the calculation of earthquake based on SNI 03-1726-2002 section 7.7.2. is the dead load of its own structure, additional dead load, and live load is 30%.

9. Calculation of nominal shear load
 Nominal shear load for static earthquake calculation can be calculated as follows:
 $Vx = \frac{c1\,x\,I}{R} 941685{,}6974$
 $= \frac{0{,}078\,x\,1}{8{,}5} 941685{,}6974$
 = 8641
 $Vy = \frac{c2\,x\,I}{R} 941685{,}6974$
 $= \frac{0{,}074\,x\,1}{8{,}5} 941685{,}6974$
 = 8198

10. Calculation of the equivalent static earthquake manually
 The magnitude of the equivalent static earthquake load can be calculated with the equation:

$$Fi = \frac{Wi\ x\ zi}{\sum_{i=1}^{n} Wi\ x\ zi} V$$

 SNI of Earthquake 03-1726-2002 section 5.8.2 mentioned that: "to simulate earthquake influence direction, plan that any of building structure, the influence of earthquake in the main direction must be considered 100% effective and must be considered to occur concurrently with the influence of earthquake loading in a perpendicular direction to the direction of that main loading with only 30% effectiveness ".

11. Coordinate calculation of mass center point

On SNI of earthquake 03-1726-2002 section 5.4.1 mentioned that capture point of static and dynamic load of earthquake was at the center of mass. To find out the coordinates of a point in the center of mass, it can be done by reducing the rotational center with eccentricity plan (ed).

12. Earthquake spectrum response plan
Determination of variety of spectrum response type refers to the SNI 03-1726-2002 section 7.2.2 as follows:
a. Concrete structure damping (*damping*) = 0,05
b. Input response spectra
Earthquake scale factor of X direction = (g x I)/R_= (9,81x1,0) / 8,5 = 1,15
Earthquake scale factor of X direction = 30% x X direction of earthquake = 0,346

13. Analysis of dynamical earthquake history
Based on SNI of earthquake 03-1726-2002 section 7.3.1. value of acceleration peak:

$$A = \frac{AoxI}{R}$$

With the value of acceleration peak of ground surface due to the influence of earthquake plan (Ao) for the earthquake area 4 with the type of medium soil is 0.28.

Thus, the magnitude of value of f $A = \frac{0{,}28x1}{8.5} = 0{,}032$

In this planning, the time history which is used is Elcentro, with peak acceleration value is 0, 3194g. And so that the Accelerogram acceleration can match the target, then the multiplier is required as follows:
a. Scale factor = (0,032/0,3194) x 9,81 = 0,9828
b. 30% upright direction = 0,294

ANALYSIS RESULT OF DESIGN

Analysis of Spectrum Response Variations

To determine the appropriate type of analysis of the spectrum response variations, the difference from the period is calculated as follows:

ΔT = Difference of period / vibration time
= (T1–T2) / T1 x 100%

TABLE 3
CALCULATION OF DIFFERENCE PERIOD (ΔT) IN EACH MODE

Mode	Period Sec	ΔT (%)
1	6,142	0,101
2	5,52	0,042
3	5,29	0,652
4	1,839	0,065
5	1,72	0,020
6	1,685	0,394
7	1,021	0,049
8	0,971	0,106
9	0,868	0,171
10	0,72	0,059
11	0,677	0,215
12	0,531	1

Service Limit Performance

In SNI of earthquake 03-1726-2002 section 8.1 states that the calculation of service limit performance due to X and Y deviation can be read from the graph or output table and it is calculated as follows:

1. Change in deviation, Δ_S = deviation of upper floor – lower floor
2. Permitted deviation = 0,03/R x relevant height level or 30 mm.

Service limit performance due to the largest static earthquake deviation of X is 8,95 mm < 11,65 mm.

Service limit performance due to the largest static earthquake deviation of Y is 11,65 mm < 23,29 mm.

Ultimate Limit Performance

In SNI of earthquake 03-1726-2002 section 8.2.1, 8.2.2, states that all deviations between levels calculated from the deviation of building structures for ultimate limits shall not exceed 0.02 times the level of the relevant level. The calculation of ultimate limit performance is as follows:

1. Multiplier factor, ξ = 0,7 x R
2. Permitted deviation,Δmax = 0,02 x H

Ultimate limit performance due to the largest static earthquake deviation of X is 53,28 mm < 66 mm

Ultimate limit performance due to the largest static earthquake deviation of Y is 69,31 mm <132 mm

Material Input of ABAQUS CAE V6.14 Program

1. Screw steel material for ABAQUS input
For material mechanical data are as follows:
Fy = 400 Mpa
Density = $7{,}82x10^9$ N/mm^3
Modulus elasticity = 200000 Mpa

TABLE 4
DATA OF STEEL PLASTICITY

Stress (MPa)	Strain
400	0
400	0.018
500	0.028
500	0.198

2. Plain steel material for ABAQUS input
For mechanical data are as follows:
Fy = 240 Mpa
Density = $7{,}82x10^9$ N/mm^3
Modulus elasticity = 200000 MPa

TABLE 5
DATA OF STEEL PLASTICITY

Stress (MPa)	Strain
240	0
240	0.02
370	0.028
370	0.168

3. Concrete materials for ABAQUS input
   For material mechanical data are as follows:
   F'c = 40 MPa
   Density = 2,4 x 10^9 N/mm^3
   Modulus elasticity = 29725,41 MPa

TABLE 6
DATA OF CONCRETE PLASTICITY (JANKOWIAK, 2014)

Concrete Compression Hardening		Concrete Compression Damage	
Stress (MPa)	**Crushing Strain (-)**	**Damage C (-)**	**Crushing Strain (-)**
15	0	0	0
20.1978	0.000075	0	0.000075
30.0006	0.000099	0	0.000099
40.3038	0.000154	0	0.000154
50.0077	0.000762	0	0.000762
40.2361	0.00255	0.195402	0.00255
20.2361	0.005675	0.596328	0.005675
5.2576	0.011733	0.894865	0.011733
Concrete Tension Stiffening		**Concrete Tension Damage**	
Stress (MPa)	**Cracking Strain (-)**	**Damage T (-)**	**Cracking Strain (-)**
1.99893	0	0	0
2.842	0.000033	0	0.000033
1.86981	0.00016	0.404641	0.00016
0.86981	0.00028	0.69638	0.00028
0.226254	0.000684	0.920389	0.000684
0.056576	0.001087	0.001087	0.001087

Modeling of Beam-Column Connections using ABAQUS CAE V6.14 Program

The following figure are the results of 3D modeling assisted by ABAQUS CAE v6.14 program:

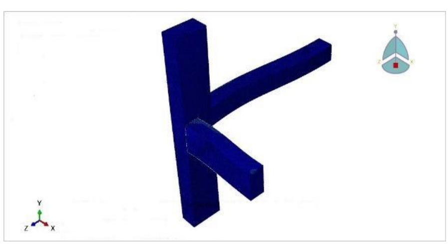


Fig. 1 Modeling of concrete beam-column connections

Analysis of Theoretical Data of Tension and Strain

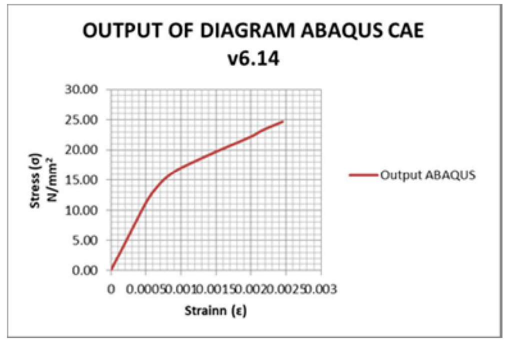
To validate the numerical test results of the ABAQUS CAE program v6.14**,** it is needed comparative data that are clear and reliable, namely theoretical data. Figure 6 shows the formula of the tension strain curve obtained from the book from Park and Paul (1975).

Numerical Data Processing (ABAQUS CAE V6.14)

The results of tension and strain analysis of the research can be seen in Table 7 and Figure 2. The table shows the maximum tension value occurred at 24.69 N/mm^2 with strain of 0.00245. The ductility value is determined from the comparative value between the ultimate strain (µu) and the melting strain (µy). From the ultimate strain comparison (µu) and melting strain (µy), the ductility value obtained is 5,26.

TABLE 7
PARAMETER OF STRAIN AND STRESS RELATIONSHIP

Yield		Ultimit	
Strain	**Stress N/mm2**	**Strain**	**Stress N/mm2**
0,000465	10,5	0,00245	24,69



The strain and tension patterns displayed are the *maximum principal plastic equivalent strain* (PE) and *maximum tensile principal stress* (S), which shows the level of stress scale strain on the beam-column relationship. *The maximum principal plastic equivalent strain* (PE) provides a better display to illustrate the level of strain tension.

Result of Comparison between Theoretical and Numerical Data

The use of theoretical data calculation aims to provide a comparison between the results of modeling. The following figures are the modeling results from the theoretical calculation inputs obtained from the ABAQUS CAE v6.14 software. The following data is the comparison between theoretical data and numerical data.

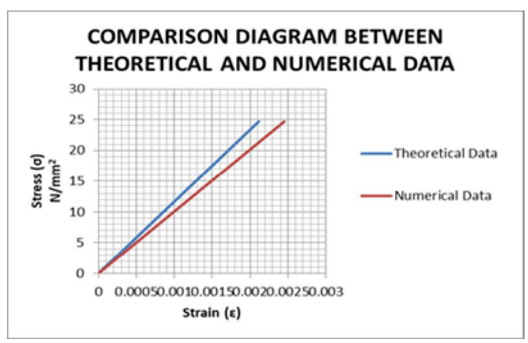


Fig. 3 Curve relationship of strain voltage based on theoretical data and numerical data

Based on figure 3, it shows that the maximum voltage value is equal to theoretical tension. The maximum value of the theoretical tension is 24.69 MPa and the strain is 0.00211, after being simulated numerically the maximum tension is 24.69 MPa, the maximum strain is 0.00245.

TABLE 8
RECAPITULATION OF NUMERICAL AND THEORETICAL TEST RESULT

Theoretical Data		Numerical Result	
Stress N/mm2	Strain	Stress N/mm2	Strain
24,69	0,00211	24,69	0,00245

It can be seen in table 8 that the value obtained from the simulation results of ABAQUS CAE v6.14 software has a small difference in voltage and a considerable difference in strain. It is because the results of numerical tests do not have good and uncommon distribution data. So that some problems occur during the simulation process, such as stretches that are too large, so they cannot be calculated.

TABLE 9
DIFFERENT VALUES OF THEORETICAL AND NUMERICAL STRAIN

Strain from Theoretical Result	Strain from Numerical Result	Differences Value
0,00211	0,00245	13,91

The difference in numerical and theoretical strain is 13.91%. It shows that there is still a lack of appropriate material parameters to describe the behavior of concrete, especially in the support modeling used, as well as the limitation of conditions used

IV.CONCLUSION

From the results of the discussion and analysis of the Marrakech Suites apartment building structure, the following conclusions can be drawn:

1. The building vibration time for mode 1 is 5.628 seconds and mode 2 is 5.336 seconds, where the maximum period for the requirement of building period limitation is 6,29 seconds so that the period limit is fulfilled.
2. Terms of maximum deviation between floors due to static earthquake and dynamic earthquake for x and y direction is 6.93, it cannot exceed the permitted deviation of 13.2 cm so that the structure is resistant to earthquakes.
3. The maximum voltage based on theoretical data (Park and Paulay) is 24.69 N/mm^2 and the maximum strain is 0.00211.
4. The maximum voltage output of the ABAQUS CAE v6.14 program is 24.69 N/mm^2 and the maximum strain is 0.00245.
5. The difference in strain value is 13.91% bigger in numerical strain than theoretical strain.
6. From the comparation between the ultimate strain (μu) and melting strain (μy), the ductility value is 5,26 which is categorized as partial ductility (μ = 1.0-5.29)

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