IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 7, July 2021

DOI: 10.17148/IARJSET.2021.8765

STUDY ON ENERGY DISSIPATION BEHAVIOR OF REINFORCED CONCRETE COLUMNS SUBJECTED TO SEISMIC LOADS

Mamatha B R[1], Dr. P M Ravindra[2]

[1]P.G Student, Department of Civil Engineering, Bangalore Institute of Technology, Bangalore-560004

[2]Professor Department of Civil Engineering, Bangalore Institute of Technology, Bangalore-560004

Abstract: The goal of this research is to better understand how energy dissipates in reinforced concrete columns when they are subjected to seismic forces. During an earthquake, the structure is subjected to some energy demand. The load bearing components, such as columns, disperse the imposed energy demand. If the RC columns energy dissipation capability is greater than the demand imposed by the seismic activity then the structure is considered to be safe and if the RC columns energy dissipation capability is less than the demand imposed then the structure may get damaged. Hence the energy dissipation capability of an RC column is the major factor need to be studied during the seismic activity. The energy dissipated by the column can be found out from the hysteresis curve obtained by plotting force-displacement graph. It has been shown from previous research that the vast majority of study were conducted using a unidirectional loading protocol. This study investigates the impact of various factors on the energy dissipation capacity of a reinforced concrete column. From this research it has been found that with an increase in axial load ratio, the energy dissipation capability of an RC column decreases. As the transverse reinforcement ratio and displacement capacity increases, it results in rise of energy dissipation in an RC column. When comparing unidirectional loading with bidirectional loading, it is found that the higher energy is dissipated in case of bidirectional loading.

Key words: Energy dissipation, Displacement capacity, Unidirectional loading, Bidirectional loading, Axial load ratio, Transverse reinforcement ratio

1. INTRODUCTION

A critical element in determining earthquake resistance is the amount of energy dissipated by RC columns, which is one of the most essential variables to consider. The damage produced by an earthquake in both directions is typically more severe than the damage caused by an earthquake in just one direction. Naturally, the seismic resistance in one path is reduced in another, and the coupling effect increases the dissipation energy in each of these directions. In advance earthquake analysis or design methods, it is critical to estimate with reasonable accuracy the cyclic activity of reinforced concrete (RC) columns, which is defined by the capacity, deformability, and quantity of wasted energy of RC elements, among other characteristics. During the analysis of force-displacement interactions, the energy lost by each material is represented by the area encompassed by a hysteresis loop. Stirrups and ties, for example, are two components that help to dissipate energy by increasing the deformation capacity and compressive strength of the system. Dissipation is a word that is used to describe the process through which energy is lost or misused. A structure should disperse the energy emitted by earthquake loads when they are applied to a structure. If the structures ability to disperse energy is reduced, the amount of damage done to the structure will be increased. The main energy under lateral stress will be enwrapped for each loading period throughout the course of the experiment. This enwrapped energy is portrayed as a kind of energy that is both dissipated and recoverable in nature. The ability of an element to regain its original phase is referred to as reclaimable energy, and it is comprised of two types of retrieval: an elastic recovery and a nonlinear retrieval. The term “Ductility displacement” refers to a comparative assessment of the element’s deforming potential, as well as the ratio of the greatest displacement gathered on initial yields in a loop to the displacement, which is measured in millimeters (Elmenshawi & Brown 2010). The relation between all of the design factors and energy dissipation has not been established in a thorough research.

2. METHODOLOGY

The objectives of this research are identification of various parameters that influence energy dissipation capability, Determination of energy dissipation capacity of RC column tested under unidirectional and bidirectional lateral loading with constant axial load and comparison of the energy dissipation of RC columns subjected to unidirectional and bidirectional loading.

The primary emphasis of this research is on the literature and on the analytical process. The study would begin with the review of the literature, namely all of the studies that have been done on RC columns having a high energy dissipation

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capability. Following the conclusion of the literature review, the data collecting procedure was initiated to gather information. In addition to the data on force-displacement acquired from University of Washington website, a little quantity of information was gathered from the research papers of Rodrigues et al. and Raza et al. There are number of geometrical features that differ from one another in data included. The area under force-displacement curve of the column was calculated using the data obtained for each loading cycle, which was conducted after the data collection was completed. During each loading cycle, the area under the hysteresis loop was calculated in order to determine its shape. The origin lab software is used to find the area under force-displacement curve. Following the computation of the area, the next step was to perform an analysis of the data that had been gathered. Following the analysis, the data was verified by plotting a graph, which confirmed the findings of this study

3. RESULTS AND DISCUSSIONS

3.1 Columns Energy dissipation calculated from experimental data

3.1.1 Energy Dissipation of columns subjected to Unidirectional loading:

In the event of seismic activity, the ability of reinforced concrete columns to dissipate energy becomes an important structural characteristic. In this particular instance, the columns were subjected to continuous uniaxial lateral loading, and the results are estimated. The following are the tables for energy dissipation for the columns:

Table 3.1: specimens tested under unidirectional lateral loading

Columns	∑E	Displacement capacity
Thomsen and Wallace A1	456	6.89
Thomsen and Wallace A3	468	6.5
Sezen and Moehle Specimen 1	67	5.6
Sezen and Moehle Specimen 2	33	2.9
Galeota AA1	5	3.64
Galeota CB3	127	9.4
Galeota CA1	44	6.4
Galeota CA2	56	5.34
Tanaka Specimen 1	121	9.1
Tanaka Specimen 5	160	5.5
Tanaka Specimen 7	273	6.03
Tanaka Specimen 9	299	6.9
Watson & Park Specimen 5	99	3.43
Watson & Park Specimen 6	46	3.01
Soesianwati Specimen 1	182	7.12
Soesianwati Specimen 3	73	4.35
Raza Specimen 1	105	5.75
Raza Specimen 2	88	4.77
Raza Specimen 3	26	2.06
Raza Specimen 4	35	2.37
Raza Specimen 5	40	2.9
Raza Specimen 6	59	3.35
Rodrigues Sp1	47.5	4.45
Rodrigues Sp2	22.5	2.65
Rodrigues Sp5	160	5.75
Rodrigues Sp6	170	6.1
Rodrigues Sp9	235	6.1
Rodrigues Sp10	185	6.4
Rodrigues Sp13	142	6.25

Source: Peer Structural performance database, Saim Raza et al. and Rodrigues et al. research papers

The energy dissipation of RC columns will vary as a consequence of changes in the transverse reinforcement ratio, axial load ratio, longitudinal reinforcement ratio, and concrete strength.

Table 3. 2: Specimen examined by Hugo Rodrigues

Column	**∑E**	**Loading path**
Rodrigues Sp9	235	Uniaxial strong
Rodrigues Sp10	185	Uniaxial Weak

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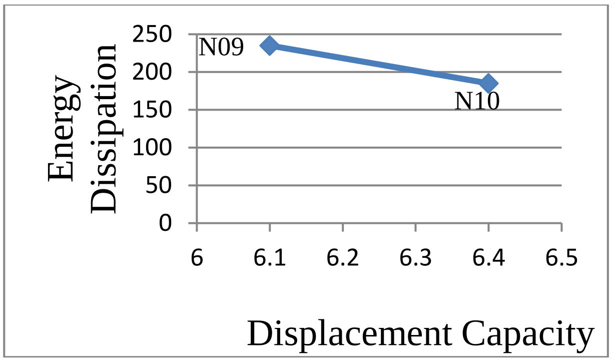

Figure 3.1: Relationship between Energy and Displacement capacity

The energy dissipated by the specimen N10 is 21% less than the amount of energy emitted by the specimen N09 this is shown in table 3.2. This decrease in energy dissipation may be due to the variation in the cross-sectional area of the supporting columns. It has a cross- section of 30*50 cm, with the depth of the strong direction being 50cm and the depth of the weak direction being 30cm. As a result, if the depth of the cross-section is higher, the energy dissipated by the column will be greater, and whenever the cross-sectional depth of the column is less, the energy dissipated by the column will be smaller.

3.1.2 Effect of axial load ratio under unidirectional loading:

When it comes to the capacity to dissipate energy, the axial load has a direct impact. It is known that energy dissipation capability of an RC column is inversely related to the axial load ratio, which implies that when there is an increase in the axial load ratio, the energy dissipation capability of the column decreases.

Table 3.3: Specimens examined by Saim Raza

Column	Axial load ratio (n)	∑E
Raza Sp1	0.25	105
Raza Sp2	0.4	88
Raza Sp3	0.55	26

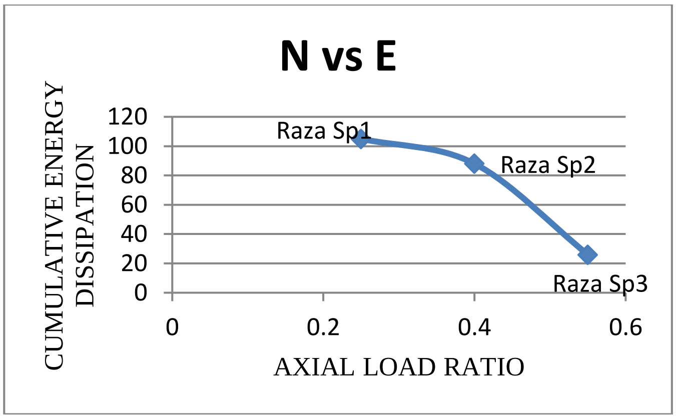

Figure 3.2: Relationship between Energy and Axial load ratio

In fig 3.2, it can be observed that when the axial load ratio increases, the energy dissipation capability falls, as shown in graph. The energy dissipated by the column decreased by 16 percent when axial load ratio increases from 0.25 to 0.4. However, the energy dissipated by the column decreased by 71 percent when axial load ratio increases from 0.4 to 0.55.

Table 3.4: Specimen examined by Sezen and Moehle

Specimen	Axial load ratio (n)	∑E
Sezen and Moehle Specimen 1	0.15	67
Sezen and Moehle Specimen 2	0.61	33

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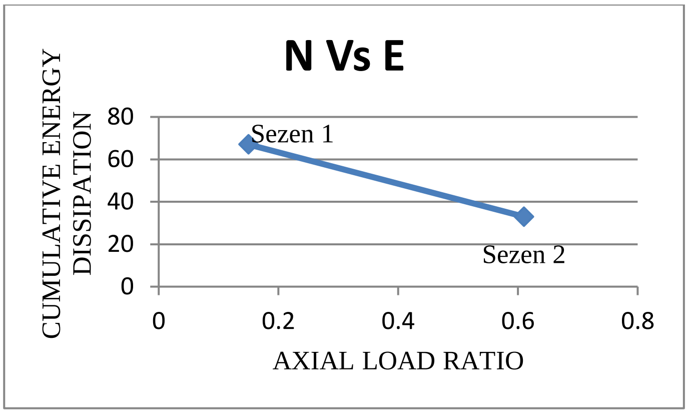

Figure 3.3: Relationship between Energy and Axial load ratio

Figure 3.3 shows that increasing the axial load ratio from 0.15 to 0.61 results in a 51 percent decrease in energy dissipation, which is consistent with the previous figure. The rise in the axial load ratio is solely responsible for the two reductions in energy dissipation mentioned above.

Table 3.5: Specimen examined by Soesianwati

Column	**Axial load ratio**	**∑E**
Soesianwati Specimen 1	0.1	182
Soesianwati Specimen 3	0.3	73

It seems that increasing the axial load ratio from 0.1 to 0.3 results in a 60 percent reduction in energy dissipation, as seen in the data in the table 3.5

3.1.3 Effect of displacement capacity under unidirectional loading:

In terms of displacement capacity, the effect of displacement capacity on column is same as that of the effect of axial load ratio. The displacement capacity of the column diminishes when the axial load ratio of the column is raised. As the axial load ratio increases from 0.15 to 0.3 it results in a reduction of displacement capacity by 17 percent, and as an axial load ratio increases from 0.3 to 0.45 it results in a reduction of displacement capacity by 57 percent as shown in figure 3.1. We can observe in figure 3.2 that increasing the axial load ratio from 0.151 to 0.605 results in 59 percent decrease in the displacement capacity. A substantial reduction in the strength of the column is caused by buckling of the longitudinal bars.

Table 3.6: Specimens examined by Saim Raza subjected to unidirectional loading

Column	**Displacement capacity**	**∑E**
Raza Sp1	5.75	105
Raza Sp2	4.77	88
Raza Sp3	2.06	26

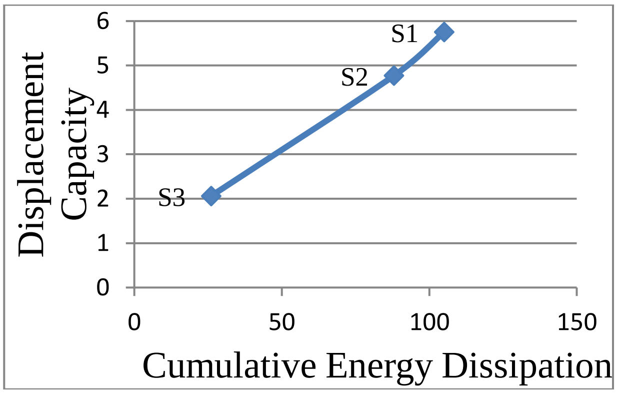

Figure 3.5: Relationship between Energy and Displacement Capacity

IARJSET

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Table 3.7: Specimens examined by Sezen and Moehle subjected to unidirectional loading

Column	Displacement capacity	∑E
Sezen and Moehle Sp 1	4.55	57
Sezen and Moehle Sp 2	1.87	23

3.1.4 Effect of transverse reinforcement ratio under unidirectional loading:

When the transverse reinforcement ratio increases, the energy dissipation capacity increases as well, but to a lesser extent. The table below shows that, as the transverse reinforcement ratio lowers from 0.0071 to 0.003, the energy dissipation decreases by 53percent.

Table 3.8: Specimens examined by Watson & Park

Column	Transverse Reinforcement ratio	Σ E
Watson & Park Specimen 5	0.0071	99
Watson & Park Specimen 6	0.003	46

Table 3.9: Specimens examined by Saim Raza

Column	Transverse Reinforcement Ratio	Σ E
Raza Sp3	0.004	26
Raza Sp4	0.0055	35

We can see from the table above that there is a 26 percent increase in energy dissipation when the transverse reinforcement ratio increases from 0.004 to 0.005, which is consistent with prior studies.

Table 3.10: Specimens examined by Saim Raza

Column	Transverse Reinforcement Ratio	Σ E
Raza Sp2	0.004	88
Raza Sp5	0.002	40

Table 3.10 shows that, when the transverse reinforcement ratio falls from 0.004 to 0.002 there is a 55 percent reduction in energy dissipation.

3.2 Dissipation of energy under bidirectional lateral loading:

As a consequence of the multi-directional nature of seismic activity, biaxial bending of columns in structures built with reinforce concrete is common. The energy dissipation values for the six columns evaluated under constant bidirectional loading are as follows:

Table 3.11: Specimens examined by Saim Raza subjected to bidirectional loading

Column	Σ E
Raza Sp7	147
Raza Sp8	97
Raza Sp9	219
Raza Sp10	113
Raza Sp11	190
Raza Sp12	103

Source: Saim Raza et al. research paper

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3.2.1 Effect of type of bidirectional loading path on Energy dissipation:

The kind of loading path examined has a significant impact on the amount of energy dissipated. In order to ensure that the columns respond appropriately to the loading, it is critical to choose a viable bidirectional loading protocol. However, there is no indication as to which method is associated with the actual displacement path of an RC column during seismic activity. Researchers have previously utilized many alternative types of bidirectional displacement paths.

Table 3.12: Specimens examined by Saim Raza.

Column	∑E	Loading Path
Raza Sp9	219	Octo-elliptical loading(1:1)
Raza Sp10	113	Octo-elliptical loading(1:1)
Raza Sp7	147	Linearized circular loading(1:1)
Raza Sp8	97	Linearized circular loading(1:1)
Raza Sp11	190	Octo-elliptical loading(1:0.6)
Raza Sp12	103	Octo-elliptical loading(1:0.6)

Raza specimen, S7 and S8 are evaluated using linearized circular loading paths, while specimens S9 to S12 are studied utilizing Octo-elliptical loading paths. When comparing specimens tested under linearized circular loading paths to specimens tested using Octo-elliptical loading paths, it shows that the amount of energy dissipated by specimens when tested under linearized circular loading path is less.

Table 3.13: Specimen examined by Hugo Rodrigues

Column	Cumulative Energy Dissipation	Loading path
Rodrigues Sp21	133	Rhombus
Rodrigues Sp22	119	Quadrangular

Table 3.13 shows that the energy dissipated by the rhombus loading path is 11percent greater than the energy dissipated by the quadrangular loading path, indicating that the rhombus loading technique is more efficient.

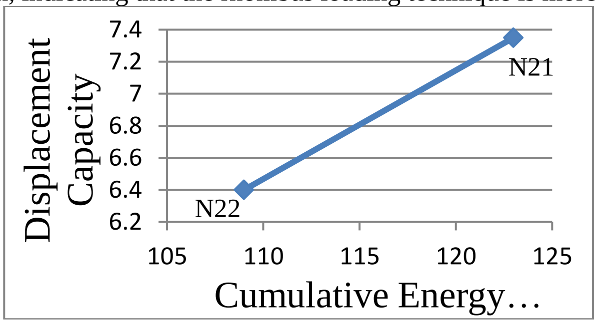

Figure 3.10: Relationship between Energy and Displacement Capacity

Tables 3.14 and 3.15 shows that the energy dissipated by the quadrangular loading path is smaller than the energy dissipated by the rhombus loading path, which is consistent with our observations.

Table 3.14: Specimen examined by Hugo Rodrigues

Column	Cumulative Energy Dissipation	Loading path
Rodrigues Sp7	210	Rhombus
Rodrigues Sp8	135	Quadrangular

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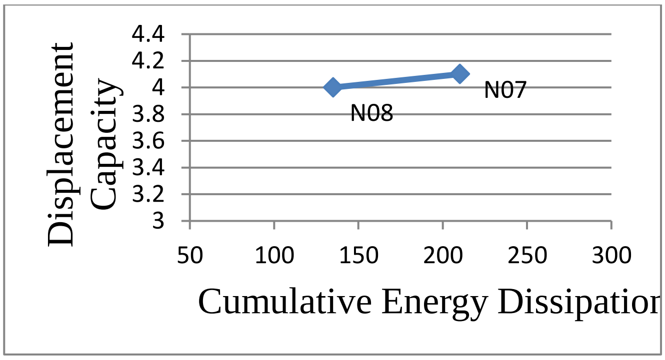

Figure 3.11: Relationship between Energy and Displacement Capacity

Table 3.15: Specimens examined by Hugo Rodrigues

Column	Cumulative Energy Dissipation	Loading path
Rodrigues Sp14	140	Rhombus
Rodrigues Sp15	125	Quadrangular

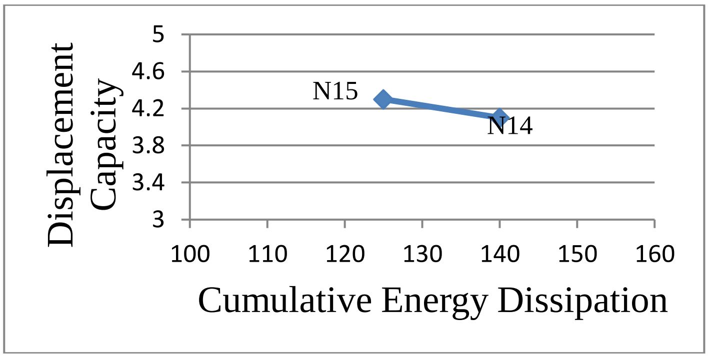

Figure 3.12: Relationship between Energy and Displacement Capacity

3.3 Comparison of unidirectional and bidirectional loading:

The energy dissipated by an RC column during bidirectional lateral loading is much more than the energy dissipated by the same column during unidirectional lateral loading. This is due to the energy is dissipated in two directions when bidirectional loading is taken into consideration. Hence when we add the energy dissipation in both the direction we get more value than the amount of energy dissipated when unidirectional loading is taken into consideration.

Table 3.16: Specimens examined by Hugo Rodrigues

Column	Energy dissipation	Drift capacity	Loading path
Rodrigues Sp13	142	6.35	Uniaxial strong
Rodrigues Sp16	160	5.2	Circular

Based on the results presented above, it is observed that the energy dissipated by Rodrigues Sp 16 subjected to circular loading procedure is greater than the specimen 13 which is subjected to uniaxial loading procedure.

Table 3.17: A Comparison on unidirectional and bidirectional loading path examined by Saim Raza

Specimen	∑E	Loading path
Raza Sp1	105	Uniaxial
Raza Sp7	147	Linearized circular loading(1:1)
Raza Sp9	219	Octo- elliptical loading(1:1)
Raza Sp11	190	Octo-elliptical loading (1:0.6)

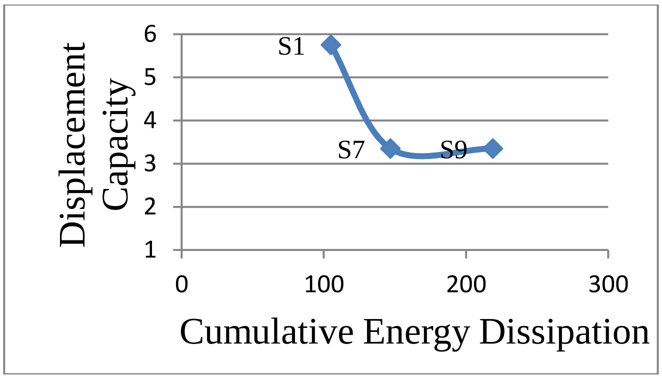

Figure 3.14: Relationship between Energy and Displacement Capacity

From table 3.17, we can observe that, the energy dissipated by the specimen exposed to bidirectional loading path is higher in contrast to the energy dissipated by the specimens subjected to unidirectional loading paths. Additionally, the energy dissipated by the specimen subjected to Octo-elliptical loading protocol is higher than the energy dissipated by linearized circular loading protocol. The energy dissipated by the specimen subjected to Octo-elliptical loading procedure (1:0.6) is slightly less than the energy dissipated by the specimen when exposed to Octo-elliptical loading procedure (1:1), due to the fact that the maximum imposed drift in the X- direction was 60% of the equivalent drift in the Y-direction.

Table 3.18: Comparison of specimens examined by Saim Raza

Specimens	**∑E**	**Loading path**
Raza Sp2	88	Uniaxial
Raza Sp8	97	Linearized circular loading(1:1)
Raza Sp10	113	Octo- elliptical loading(1:1)
Raza Sp12	103	Octo-elliptical loading(1:0.6)

In table 3.18, it can be seen that when the specimen S2 is subjected to unidirectional loading, the energy dissipated by the specimen is less than when the specimens are subjected to other bidirectional loading procedures, and Octo-elliptical loading protocol (1:1) has a 14 percent higher energy dissipation than the energy dissipation of the specimen subjected to the linearized circular loading path.

4. CONCLUSIONS:

The following conclusions are drawn from this study:

- ❖ The energy dissipation capability of RC column decreases by 30 – 60 percent with increase in axial load ratio ranging between 0.05 and 0.605.
- ❖ It is estimated that energy dissipation rises by 40- 60 percent with increase in displacement capacity.
- ❖ An increase in the transverse reinforcement ratio ranging between 0.002 and 0.012, results in increase in energy dissipation of 45-55 percent.
- ❖ When comparing unidirectional loading with bidirectional loading, it is found that the higher energy is dissipated in case of bidirectional loading.
- ❖ The circular loading procedure dissipated more energy when compared to the other bidirectional loading procedure, while the quadrangular loading procedure dissipated the least energy when comparing to the other loading techniques.

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