

ENERGY DISSIPATION IN INTERLOCKING GROUTED STABILISED MUD BLOCK MASONRY UNDER CYCLIC UNIAXIAL COMPRESSIVE LOADING

B.K.Singh¹ and S.N. Sinha²

Abstract

This paper presents the results of experimental investigation on interlocking grouted stabilised mud block masonry subjected to cyclic uniaxial compressive loading related to its energy dissipation characteristics. Energy dissipation is usually expressed as non-dimensional ratio defined as the energy dissipated per cycle to the energy supplied in that cycle. The interlocking brick/block and masonry developed by Prof. S.N. Sinha has been used in this study. Total of fourteen specimens of size 600mm×200mm×750mm were tested for loading perpendicular and parallel to bed joints. The energy dissipation ratio (EDR) versus envelope strain ratio and plastic strain ratio were found to exhibit three typical ranges showing distinct trends. Mathematical models are proposed for the relations between EDR and envelope and residual strain ratios.

Key Words

Cyclic loading, energy dissipation, interlocking blocks, grouted masonry

Notation

a_1, a_2, a_3	= equation's constant
EDR	= energy dissipation ratio
e	= axial strain
e_m	= axial strain corresponding to ultimate stress
f	= axial stress
f_m	= peak axial stress
r	= coefficient of correlation

¹Research scholar, Dept. of Civil Engineering, Indian Institute of Technology Delhi, New Delhi-110016, India. E-mail: binodkrs@yahoo.com

²Professor, Dept. of Civil Engineering, Indian Institute of Technology Delhi, New Delhi-110016, India. E-mail: snsinha@civil.iitd.ac.in

ε	= normalised strain with respect to strain corresponding to ultimate stress
ε_e	= non-dimensional envelope strain
ε_r	= non-dimensional plastic strain

1 Introduction

Cyclic loading test on masonry provide vital information related to material ductility. The cumulative energy dissipation is used as a measure of structural seismic performance. The concept of energy dissipation capacity as a measure of structural performance has been used in reinforced concrete members and masonry panels (Al Shabani and Sinha 1999, Brown and Jirsa 1971, Baron et al 1981, Hindalgo et al 1979, Darwin and Nmai 1986, Gosavi et al 1977, Naranie and Sinha 1989, Sinha and Naranie 1991). The cumulative low energy dissipation indicates the brittle behaviour of structure while high-energy dissipation before failure indicates ductile behaviour. In the inelastic range, only a part of the energy absorbed by a material is recoverable. Energy is dissipated in permanently deforming the material and is lost in heat and sound. Energy dissipation is usually expressed as non-dimensional ratio (Al Shabani and Sinha 1999, Hindalgo et al 1979, Naranie and Sinha 1989) defined as the energy dissipation per cycle to the total input energy absorbed by a material in the cycle.

This paper presents the results of an experimental investigation on the behaviour of interlocking grouted stabilised mud block masonry under cyclic uniaxial compressive loading related to its energy dissipation characteristics. The test results indicate that the energy dissipation ratio, EDR increases faster at initial loading stage and then increases slowly with increase in strain before visible cracks. At the onset of visible cracks, the EDR showed a significant increase owing to the further increase in displacement. The graphs of EDR versus envelope strain ratio and EDR versus plastic strain ratio are presented. Mathematical models are also suggested by curve fitting of test data.

2 Experimental Program

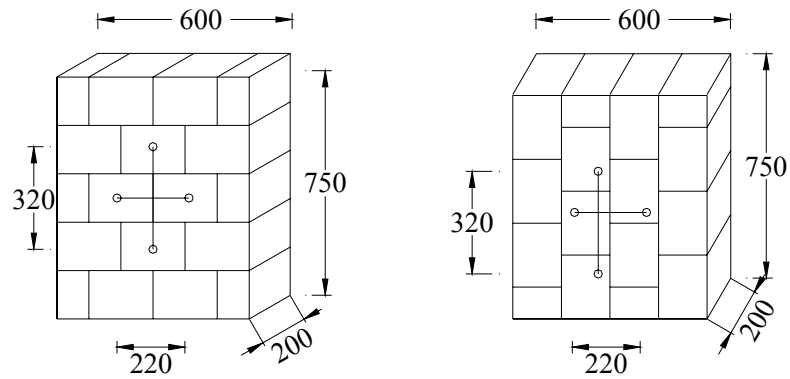
The experimental program involves testing of interlocking grouted stabilised mud block masonry of dimension 600mm×200mm×750mm constructed with interlocking blocks of size 200mm×200mm×150mm under cyclic uniaxial compressive loading. Fourteen specimens were tested for loading perpendicular and parallel to bed joints.

2.1 Test Specimen

Test specimens were made by the method developed by Prof. S.N. Sinha by interlocking blocks in stretcher bond. Layers of blocks were placed one after another without any mortar between them. It was self-aligned due to interlocking of blocks. Then the cement grout was poured into the joint from the top, which spread all over and provided adequate bond. Three grout cubes of 70mm size (control specimens) were also made for each specimen. There after, all specimens along with control specimen were cured for 28 days. All specimens were capped with gypsum plaster before test. The details of test specimen are shown in Figure 1.

2.2 Loading arrangement

The interlocking grouted block masonry specimens were tested using a rigid self-equilibrating frame of capacity 3000KN. Axial load was applied with the use of two hydraulic jack of same capacity connected to a single hydraulic pressure control unit in parallel. To minimize the effect of platen resistant, 10mm thick teflon sheets were placed on both bearing surfaces of the specimen. A 3000 KN capacity load cell was placed between loading frame and the centre of steel box as shown in Figure 2.



(a) Load normal to bed joint (b) Load parallel to bed joint

Figure 1 Details of test specimen

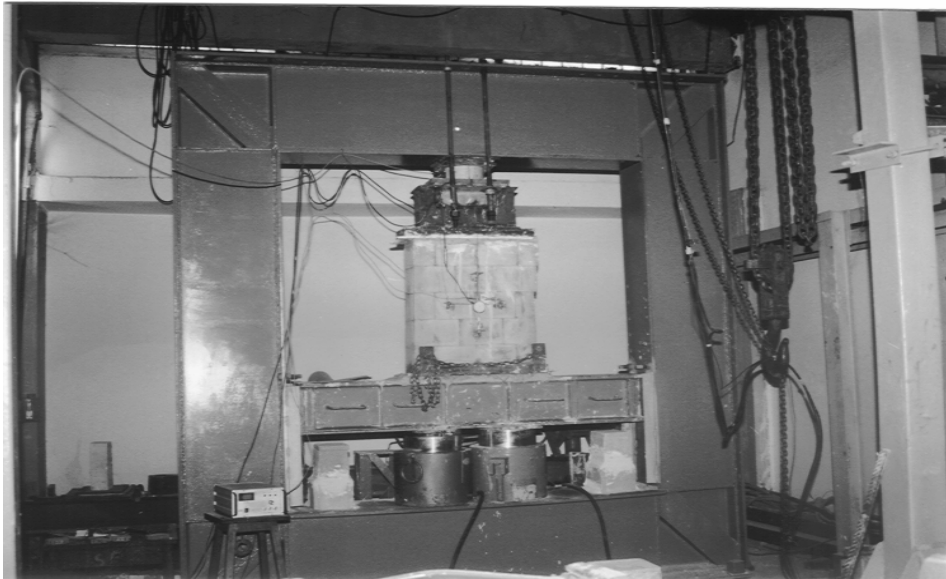


Figure 2 Test set-up

2.3 Instrumentation

The test specimens were instrumented for the measurement of axial and lateral displacements along the fixed gauge lengths. It was measured with LVDTs aligned in mutually orthogonal directions on both the side of the panel (Figure 1). A gauge length of 320mm and 220mm was adopted for measurement of axial and lateral deformations respectively. LVDTs were glued in position using araldite, an epoxy resin.

Two X-Y1-Y2 plotters were used to monitor the axial and lateral deformations at two locations on each side of the specimen. All displacement transducers and load cell were also connected in parallel to data acquisition system that was connected with P.C. This was used to display, monitor and record the load and displacement measurements in real time.

2.4 Stress-strain hysteresis

Three types of test were conducted for both cases of loading. Test type I was monotonic uniaxial loading test in which load steadily increased to failure at a constant rate. Failure load of the specimen was reached in about 3 to 5 minutes. Test type II was cyclic test in which the load was released when its peak coincided with the envelope curve from the monotonic test. This type of test resulted in a stress-strain curve with a locus of common points. Common point is defined as the point of the intersection of loading and unloading curve of previous cycle. A typical common point test is shown in Figure 3. Test type III was stability point test, which is similar to cyclic test type II except that the reloading and unloading was repeated several times in each cycle of loading. Each time unloading was done when the reloading curve intersected the initial loading curve, until such descending points of intersection stabilized. Loci of common point was kept forming in descending order and stabilized at lower bound. Further cyclic led to formation of closed hysteresis loops. Such lower bound points are termed as stability points. Peak axial stress, f_m , axial strain corresponding to peak stress, ϵ_m and mechanical characteristic of masonry materials are given in Tables 1 and 2.

Table 1 Stress-strain parameters of masonry

Loading type	Average value of f_m (Mpa)	Standard deviation (Mpa)	Average value of ϵ_m	Standard deviation	No of Sample tested	Masonry to unit strength ratio
Load normal to bed joint	11.76	1.17	3.037×10^{-3}	0.389×10^{-3}	7	0.702
Load parallel to bed joint	11.52	0.48	3.100×10^{-3}	0.374×10^{-3}	7	0.693

Table 2 Mechanical characteristics of masonry materials

Material	Mean strength	Standard deviation	No of units tested
Block	16.63	1.4	50
Grout	39.99	6.1	42

3 Energy Dissipation Capacity

3.1 EDR

The energy dissipation ratio, EDR is defined as the ratio of the energy dissipated to the total stored strain energy per cycle of loading-unloading as shown in Figure 4. The area under the curves was determined using digital planimeter. Average of the three readings were used for calculation of EDR and plotted against the non-dimensional envelope strain, ϵ_e at the peak of each cycle and also against the non-dimensional plastic strain, ϵ_r at the end of unloading curve in each cycle.

3.2 EDR against envelope strain and plastic strain

Figures 5 and 6 show the plot of ϵ_e versus EDR and ϵ_r versus EDR respectively for both cases of loading. A general mathematical model is proposed for the plot of the Figures 6 and 7 to best fit the experimental data. The expression can be written in the following general form:

$$EDR = \frac{a_1 \epsilon}{1 + a_2 \epsilon + a_3 \epsilon^3} \quad (1)$$

EDR is the energy dissipation ratio;
 ϵ is non-dimensional strain ratio ϵ_e or ϵ_r ;
 a_1, a_2, a_3 are equation's constants.

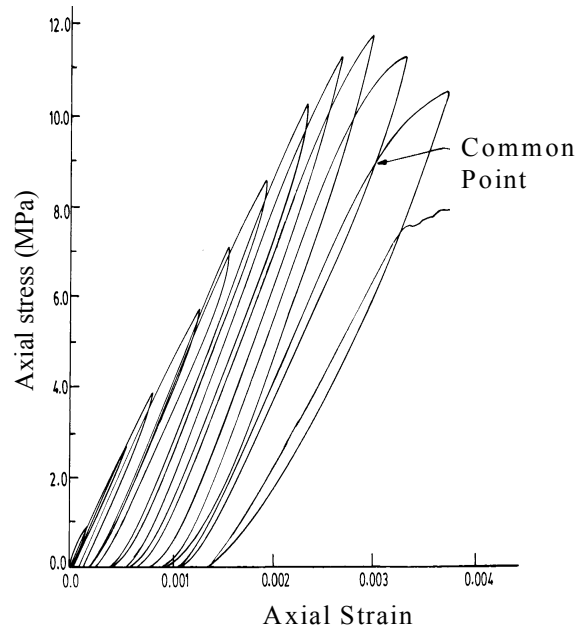


Figure 3 Typical common point test

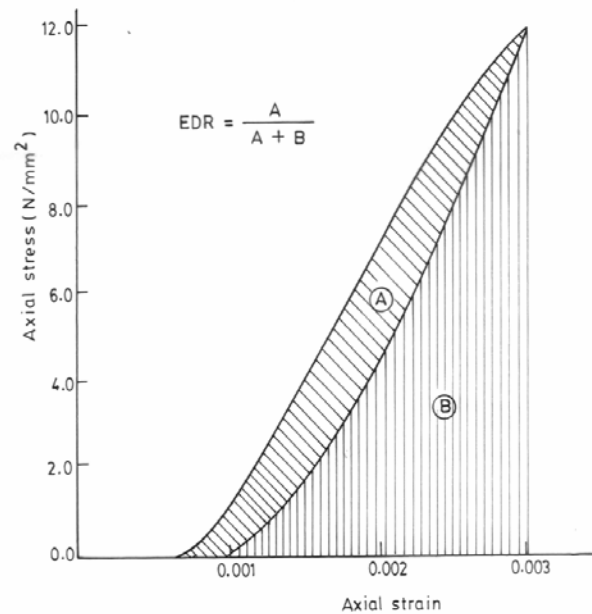


Figure 4 Determination of EDR

The value of equation's constants is presented in Table 3. The correlation coefficients, r between the analytical curves and the test data is also presented in the Table 3. The correlation coefficient for the different plots ranges between 0.85 to 0.87 indicate a good correlation between the test data and the analytical curves as EDR varies greatly, even for the same material because of the workmanship, internal defects in the masonry, temperature, humidity, loading rate, stiffness of machine, spring stiffness of transducers etc.

Envelope strain ratio versus EDR and plastic strain ratio versus EDR are found to exhibit three typical zones. Zone I, a faster rate of increase in the EDR with increase in the envelope or the plastic strain ratio; Zone II, a slow rate of increase in EDR with increase in envelope or plastic strain ratio; and Zone III a fast rate of increase of EDR

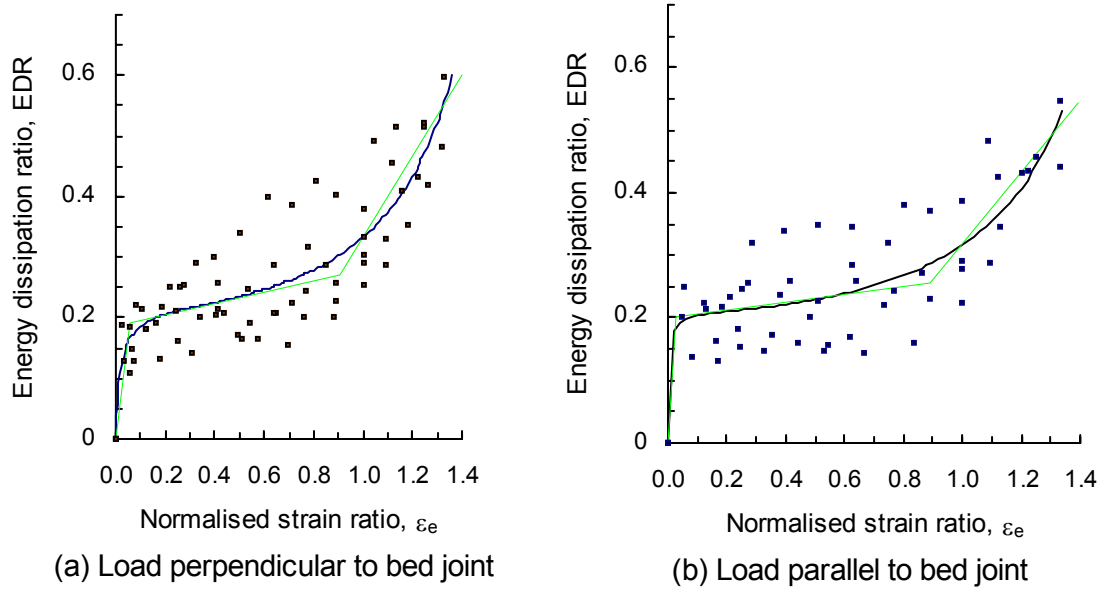


Figure 5 Envelope strain versus EDR curve

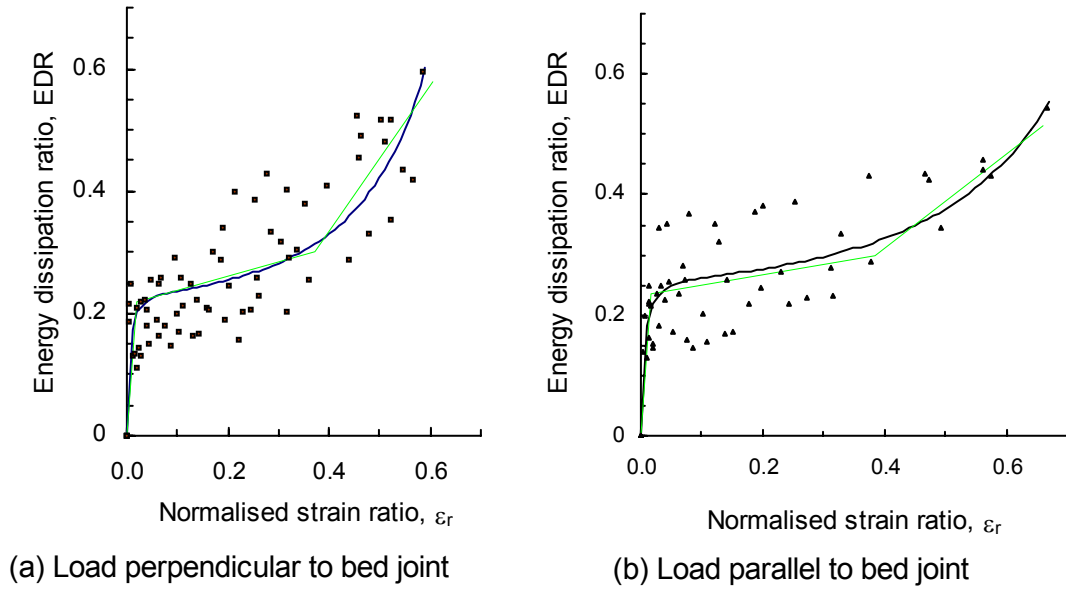


Figure 6 Plastic strain versus EDR curve

Table 3 Values of a_1 , a_2 , a_3 and r

Curve	a_1	a_2	a_3	r
EDR versus ε_e normal to the bed joint	10.820336	48.276703	-16.763078	0.885068
EDR versus ε_e parallel to the bed joint	56.305364	266.51173	-89.577899	0.87064598
EDR versus ε_r normal to the bed joint	60.681125	250.6911	-434.87481	0.8573180
EDR versus ε_r parallel to the bed joint	57.139191	211.2254	-244.575	0.8600743

with increase in envelope or plastic strain ratio.

For loading perpendicular to the bed joint, EDR ratio increases faster up to a value of approximately 0.19 corresponding to an envelope strain ratio of approximately 0.06. After which it increases slowly up to a value of approximately 0.27 corresponding to an envelope strain ratio of 0.90 then it increases faster up to a value of approximately 0.60 corresponding to an envelope strain ratio of 1.30. For loading parallel to the bed joint, EDR ratio increases faster up to a value of approximately 0.20 corresponding to an envelope strain ratio of 0.05; after which it increases slowly, approximately up to 0.26 corresponding to an envelope strain ratio of approximately 0.88; and then it increases faster up to the value of 0.55 corresponds to an envelope strain ratio of approximately 1.32.

It may be noted that the relationship between EDR and plastic strain ratio, ε_r is similar to EDR and ε_e behaviour. For loading perpendicular to the bed joint, EDR ratio increases faster up to a value of approximately 0.22 corresponding to a plastic strain ratio of approximately 0.02. After which it increases slowly up to a value of approximately 0.30 corresponding to a plastic strain ratio of 0.37 then it increases faster up to a value of approximately 0.60 corresponding to a plastic strain ratio of 0.58. For loading parallel to the bed joint, EDR ratio increases faster up to a value of approximately 0.23 corresponding to an envelope strain ratio of approximately 0.02; after which it increases slowly, approximately up to 0.32 corresponding to a plastic strain ratio of approximately 0.40; and then it increases fast up to the value of 0.55 corresponds to a plastic strain ratio of approximately 0.55.

The relatively high rate of increase of the EDR ratio at the initial stages of cyclic loading can be associated with formation of micro cracks at the interface of grout and block of interlocking grouted block masonry. The formation of these micro cracks in grout does not result in much accumulation of plastic strain in zone I. Very slow Increase in EDR With increase in envelope strain or plastic strain in zone II is because of small dissipation in energy and micro cracks in masonry. As the micro cracks get connected and the cracks widen, large plastic strains are developed in zone III.

4 Conclusions

This paper describes the energy dissipation behaviour of interlocking grouted stabilised mud block masonry tested under cyclic uniaxial compressive loading. The graph of EDR against plastic strain and EDR against envelope strain was drawn. They are found to exhibit three typical zones. Energy dissipation is faster in zone I due to micro cracks in grout, energy dissipation is slow in zone II due to micro cracks in masonry and it is faster in zone III due to interconnection of micro cracks and widening of cracks. A mathematical model is also proposed for these curves.

References

- Al Shabani, M.M., Sinha, S.N., 1999, Stress-strain characteristics of brick masonry under uniaxial cyclic loading, J. of Struct. Eng., ASCE, Vol. 125, No. 6, 600-604.
- Brown, R.H., Jirsa, J.O., 1971, Reinforced concrete beams under load reversals, J. of American Concrete Inst., Vol. 68, No. 5, 380-390.
- Baron, H., Biggs, J.M., Irvine, H.M., 1981, Seismic damages in reinforced concrete frames, J. of Struct. Div., ASCE, Vol. 107, No. ST-9, 1713-1729.
- Hindalga, P.A., Mayes, R.L., Mc Nivan, H.D., Clough, R.W., 1979, Cyclic loading tests of masonry single piers, Vol. 3- Height to Width ratio of 0.5 EERC Report No. 79/12, University of California, Berkely.
- Darwin, D., Nmai, C.K., 1986, Energy dissipation in RC beams under cyclic loads, J. of Struct. Eng.Div, ASCE, Vol. 112, No. 8, 1829-1845.

- Gosavi, N.K., Brown, R.H., Jirsa, J.O., 1977, Shear requirements for load reversals of RC members, J. of Struct. Div., Proc. of the ASCE, Vol. 103, No. ST-7.
- Naranie, K. S., Sinha, S.N., 1989, Energy Dissipation In Brick Masonry under Cyclic Compressive Loading “, Proc. 2nd Int. Masonry Conference, London.
- Sinha, S.N., Naraine, K.S., 1991, Energy dissipation in brick masonry under cyclic biaxial compressive loading, Proc. Inst. of Civil Engrs, Part 2, 173-181.
- Senthival, R., Sinha, S.N., Madan, A., 2000, Energy dissipation in high strength brick masonry under cyclic compressive loading, Proceedings of International Conference on Civil Engineering, Indian Institute of Science, Banglore, India, Vol.2, 109-119.