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DAMAGE ASSESSMENT OF REINFORCED CONCRETE STRUCTURAL WALLS USING FRACTURE BASED FRACTAL ANALYSIS

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Abstract: Shear walls are preferred in RC tall buildings to provide stability to the building and also to resist both gravity and lateral loads. In nuclear power plant structures shear walls are essential components in the designs. Research efforts on structural walls have been increasing since the past two decades. The main aim is to understand the behaviour of RC walls using experimental and numerical modelling. Analysis of post failure response and assessment of damage quantitatively in such shear walls is of utmost concern. This paper focuses on understanding the behaviour of RC structural walls under various loading conditions and performance assessment using fractal analysis. The topography of the fracture surface of concrete in the structural shear walls is characterized by using the fractal dimension. As the failure of concrete structural walls and crack patterns can be idealized as fractals, a damage index based on fractal analysis has been developed. This damage index clearly classifies the behavioural difference of such structural shear walls in a simple approach. Damage index has been calculated for tested shear walls using various parameters. Damage index has been influenced by the aspect ratio of wall, strength of concrete, shape of wall, boundary elements, and percentage of reinforcement. A detailed classification based on performance levels of structural shear walls with respect to damage index is described.

1 INTRODUCTION

Reinforced concrete structural walls are the critical structural components in buildings to withstand both gravity loads and lateral loads developed by wind and earthquake forces. In typical RC buildings, it is in the form of shear walls or core walls for lifts or staircases. These walls are characterised by providing sufficient strength, deformation, and energy dissipation capacities under severe seismic excitations to prevent collapse and casualties. After severe earthquake or some other mode of failure, the walls are to be evaluated for their residual strength and performance levels. Fractals can be used as a simple direct measurement tool in determining the remaining life of the walls.

2 RESEARCH SIGNIFICANCE

The damage in RC shear walls and their behavior can be characterized by a damage index. The damage index is a function of fractal dimension of initial and final stages of the concrete walls. Values of the fractal dimension depend on the final crack patterns of the fractured walls. Crack patterns of 27 walls have been analyzed and fractal analysis carried out. The fractal analysis has been performed using the software CMEIAS jFrad.

3 FRACTAL ANALYSIS

3.1 Introduction

Fractals are a tool describing the self-similarity in a geometric object or a physical system. The term "Fractal" was first introduced by Mandelbrot to indicate objects whose complex geometry cannot be characterized by an integer dimension. Fractals are complex and irregular geometric figures that cannot be described in terms of classical geometry or an integer dimension. Such complex geometric figures are characterized by having copies of themselves at different scales randomly, that is, they have a fine structure. Typical fractal images are shown in Figures 1 and 2.

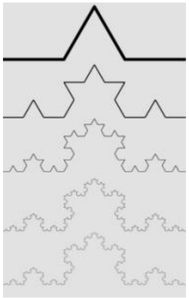

Figure 1: Koch curves

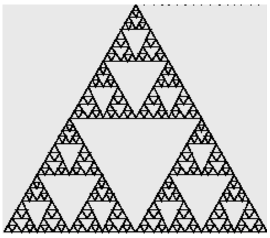

Figure 2: A Sierpinski triangle

Fractal geometry has been widely used for the description of irregular phenomena in various scientific fields recently. As remarked in the characterization of fracture systems, fractals are used to represent damaged domains.

The fracture process in concrete materials cannot be idealized in a Euclidean framework, due to its complex morphology at the micro and meso level. Fracture surfaces formed exhibit the property of self-affinity as the inherent flaws interact. Moreover, the self-organized network of micro cracks displays fractal properties prior to the formation of the final fracture surface. Due to the presence of pores and voids, the stress carrying cross-section is a rare field fractal domain, even from the beginning of the loading process [1].

The Fractal Dimension, FD, is a mathematical parameter that measures the geometric complexity level of a pattern and hence can be used to quantify the damage of concrete structures. The box-counting method is a numerical procedure for estimating approximately the fractal dimension of a geometrical pattern. Such method considers the properties of space filling of the geometrical pattern as complexity indicator. By means of such approach, the pattern is filled by a group of square boxes, and the number of elements of a particular size r is computed for estimating how many of such elements are necessary to fill the whole curve. As the size of the area element is close to zero, the total area filled by the area elements will indicate the measure of the fractal dimension. The below equation gives fractal dimension where N(r) is the total number of boxes having a r size required to fill totally the curve [2].

$$FD = \lim_{r \to 0} \left(\frac{\log N(r)}{\log \frac{1}{r}} \right) \tag{1}$$

3.2 Experimental database

The database consisting of 27 structural shear walls and their parameters are grouped in Table 1 [3-9]. Initial and final photographs of the experiments are borrowed from the literature. The database consists of walls with varying aspect ratio (h_w/l_w), axial load ratios, and different types of reinforcement and with different reinforcement ratios.

Table 1: Experimental database

Specimen id	h_w/l_w	ax	V(KN)
W-MC-C	2.4	0.10	725
W-MC-N	2.4	0.10	690
SW1	2.1	0.26	834
SW2	2.1	0.26	1062
SW3	2.1	0.25	1091
SW4	2.1	0.26	1007
SW5	2.1	0.32	1136
MQE188EP-01	0.9	0.04	355
MQE257EP-02	0.9	0.04	410
MFIEN3EP	0.9	0.04	420
1	1.1	0.00	510
1.5	1.8	0.00	342
2	2.6	0.00	274
W7	0.5	0.00	203
W9	0.5	0.00	177
W 11	0.5	0.00	173
w 13	0.5	0.00	158
RCSW1	0.9	0.13	1532
RCSW2	0.9	0.06	1102
RCSW3	0.9	0.13	1518
RCSW4	0.9	0.13	1495
RCSW5	0.9	0.00	686
RCSW6	0.9	0.00	672
SW7	2.5	0.24	201
SW8	2.5	0.35	224
SW9	2.5	0.24	304
SRCW12	2.5	0.35	266

3.3 Cracking pattern

The crack patterns in the walls have been digitized. The crack patterns were marked during the test and further the photos are converted to black and white for further fractal analysis.

3.4 Calculation of Fractal dimension

Box dimension values are taken from the CMEIAS jFrad software [10]. The box counting method was selected for estimating fractal dimension because of the random propagation of cracking on wall surface, that is, lines representing cracks intersect. The image processing in the software undergoes five steps. Binarizing image, removing additional particles and removing holes and finally, border with crack outlines. Initial and final box dimension values are predicted from the software. Figures 3 and 4 shows the final cracked image of wall and final input image for fractal dimension respectively.

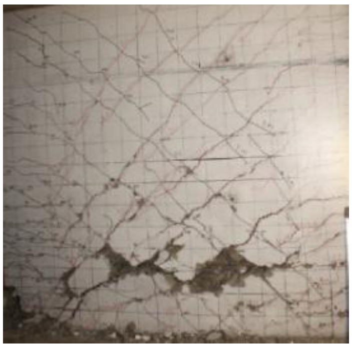

Figure 3: Crack pattern of RCSW5 at failure

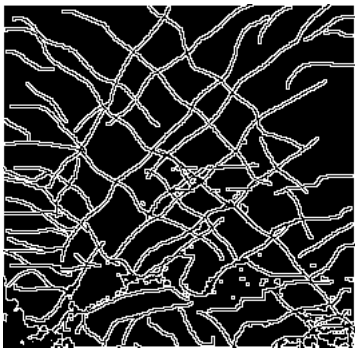

Figure 4: Crack pattern of RCSW5 for FD calculation

3.5 Calculation of Damage index

A damage index is developed using the initial and final box dimension values. Damage index is the function of difference in fractal dimension values. The maximum value for the fractal dimension of line is 2. Hence by incorporating all the above, the following expression gives the fractal dimension value.

$$DI = \frac{FD_f - FD_i}{2 - FD_i} \tag{2}$$

DI value is calculated for all 27 walls and listed in Table 2. Behavior of the walls and their performance can be predicted from DI values.

Table 2: Fractal properties of walls

Specimen id	FD_i	FD_f	DI
W-MC-C	1.26	1.77	0.69
W-MC-N	1.23	1.74	0.66
SW1	1.00	1.45	0.45
SW2	1.03	1.61	0.60
SW3	1.01	1.70	0.69
SW4	1.02	1.60	0.60
SW5	1.02	1.64	0.63
MQE188EP-01	1.03	1.60	0.59
MQE257EP-02	1.16	1.49	0.39
MFIEN3EP	1.16	1.64	0.57

1	1.01	1.63	0.63
1.5	1.30	1.66	0.51
2	1.02	1.69	0.68
W7	1.03	1.57	0.55
W9	1.00	1.51	0.51
W 11	1.03	1.55	0.54
W 13	1.02	1.55	0.54
RCSW1	1.04	1.68	0.67
RCSW2	1.03	1.65	0.64
RCSW3	1.03	1.64	0.63
RCSW4	1.03	1.77	0.76
RCSW5	1.15	1.78	0.74
RCSW6	1.03	1.75	0.74
SW7	1.02	1.58	0.58
SW8	1.02	1.58	0.57
SW9	1.01	1.61	0.60
SRCW12	1.02	1.57	0.56

4 RESULTS

4.1 Axial load ratio

The influence of axial load ratio in damage index varies with aspect ratio (h_w/l_w) of the walls. For squat walls whose aspect ratio is less than 2.0, the damage index has decreasing trend with increase in axial load ratio, whereas in slender walls ($h_w/l_w>2$) it has increasing trend with increase in the axial load ratio.

4.2 Aspect ratio

The damage index values are directly proportional to the aspect ratio of walls. When no axial load is given, the DI values increase with the h_w/l_w ratio.

4.3 Shear capacity of the walls

The damage index of the walls has increasing trend with respect to its shear capacity. As the shear capacity is a function of both axial load ratio and aspect ratio, for constant axial load there has been an increase in DI value with increase in V values. Similarly for constant aspect ratios, DI values show increasing trend with the shear capacity.

4.4 Performance of the walls

The final damage of the walls can be clearly determined from the damage index. Irrespective of all parameters, when DI values range between 0.5 and above, it can be clear that walls had reached their ultimate capacity.

5 DISCUSSIONS

The behavior of walls can be clearly understood from DI values predicted. When further more data points are added to the database a well-defined relation between the parameters and fractal dimension can be correlated, which further predicts actual behavior of the walls. Moreover the damage index based on fractal dimension can be taken for evaluating the remaining life of walls. The performance levels of walls can also be formed with respect to these DI values.

6 CONCLUSION

The damage index based on fractal dimension can be further extended to the whole structure. Just using the final damage photographs, one can assess the behavior and remaining life of structure. This idea can further be extended to structural health monitoring techniques and also rough estimate of the remaining life of the structure can be determined through simple means of photographs.

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