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DUCTILITY-IRREGULARITY CORRELATION APPROACH FOR BUILDING FRAMES

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ABSTRACT

The objective of this paper is the investigation, through an extensive parametric study, of the response of building frames to seismic loading in respect to various design parameters, as well as proposals of design recommendations for the seismic building codes. The parameters considered refer to the distribution of stiffness, strength and mass over the height of the building, and the geometric configuration of the frame. An energy approach for a realistic determination of the ductility factor of building frames is presented. A definition of an index for a quantitative estimation of the irregularity (or regularity) degree of a structure. through simply measurable quantities, is proposed.

KEYWORDS

Seismic Design, Seismic Codes, Plane Building Frames, Elastoplastic Second Order Analysis, Ductility Factor, Behaviour Factor, Regularity Factor, Energy Methods.

INTRODUCTION

Earthquake engineering, is requiring, building structures to be designed to sustain post-elastic deformations during strong earthquake events. As part of the input seismic energy is dissipated hysteritically and the kinetic energy of the structure is reduced, the design forces, compared to the linear elastic forces, can be taken according to aseismic codes significantly smaller, and lead to a more economical design. This reduction is expressed in most codes through the wellknown behaviour factor q, strongly depended on the energy dissipation capacity of the structural system, and/or the ductility of the structural members and their connections.

In aseismic codes, linear elastic analysis is usually required and the non-linear behaviour of the structure is taken into account by the introduction of the global behaviour factor q. The value of the factor q is depending on various parameters like the type of the framing structure, the type of the material, the geometric configuration, the local ductility of the members, the stiffness and strength distribution, the capacity design criteria, the overstrength etc. All these parameters, affecting the response of the building frames, can be classified in two categories, structural parameters and/or geometric parameters.

Structural and/or geometric irregularity give an indirect characterisation of the structure as regular or irregular. Modern codes (EC8, 1993) consider usually the regularity as a precondition for an improved seismic behaviour and impose penalties in the form of small behaviour factor, i.e. larger design seismic forces, when the general criteria of regularity that have been introduced are not satisfied.

In spite of the unquestionable importance of "higher" regularity to a "better" seismic response of building structures, the assessment of the various types of irregularities in seismic codes is unsatisfactory. So, further research work is necessary in this direction in order to codifying in a quantitative way the most important parameters constituting the degree of (ir)regularity. At the moment, a systematic effort is being developed on an international scale, for the definition of regularity/irregularity concept for a structure.

In this paper a method for the evaluation of the behaviour factor of moment resisting building frames, based on an energy approach is presented. A definition of an index for the quantitative estimation of the degree of (ir)regularity of a building structure through simple measurable quantities is also given, while an attempt is made for the correlation of the (ir)regularity index to the ductility factor. The whole process is realised through the methodology described below.

ANALYSIS METHOD

For the analysis of the building frames under seismic actions and the calculation of the critical response parameters, elastoplastic 2nd order analysis was used. For that purpose, a specific, research oriented, computer software has been developed within the frame of an ongoing research in the Institute of Structural Analysis and Aseismic Research of NTUA, following the steps below:

- Application of vertical forces; determination of internal forces and moments.
- Application of lateral ,forces in accordance to the fundamental shape mode up to the formation of the first plastic hinge due to lateral+vertical forces.
- Application of lateral forces according to the new fundamental shape mode up to the formation of the second plastic hinge due to lateral+vertical forces.
- Repetition of the above procedure up to "failure".

In each step of the procedure, lateral forces due to P-Δ effects have been taken into account.

The limit state definition is based on the following criteria:

- Loss of stability due to transformation of the frame into a mechanism
- Exceedance of the rotation capacity of a member
- Exceedance of interstory drift limitation (2.5%)

DUCTILITY AND BEHAVIOUR FACTORS

The global structural response is usually represented by means of the base shear-top displacement diagram (Fig. 1). In order to approximate the behaviour of the structure by a bilinear diagram O-P-U which is commonly used in seismic design, the point P corresponding to as quasi "yield" state is defined.

The ductility factor in terms of displacement is usually determined as $\mu_\delta = \delta_u / \delta_p$.

For single degree of freedom bilinear systems the relationship between μ_δ and q has been established (Newmark *et al.*, 1982):

- for shord period structures (ascending branch of the linear elastic spectrum):

$$q = \sqrt{2\mu_\delta - 1} \tag{1}$$

- for long period period structures (remaining part of the spectrum):

$$q = \mu_\delta \tag{2}$$

[illegible]

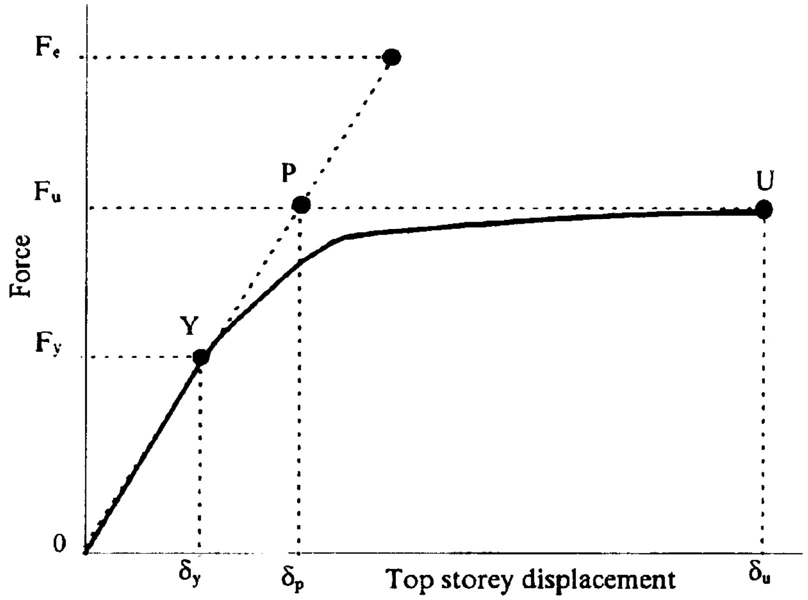


Fig 1. Base shear-top displacement diagram.

Extension of the above definitions to MDOF structures is not reliable, as no equivalent relationship can be defined, as the use of the top storey diagram for the μ_δ estimation does not necessarily cover the response of the whole structure.

For a better approach, a new definition is proposed in this paper for the ductility factor in terms of energy:

$$\mu_E = \frac{E_u}{E_y} \tag{3}$$

where:

E_u is the energy under the F-δ characteristic curve (area 0-Y-U-δ_u), and
E_y the energy at the quasi yield situation (area 0-P-δ_p)

LOCAL DUCTILITY

For moment resisting frames considered in this paper, local ductility may be expressed by the rotation capacity of plastic hinges at member ends. For analysis purposes, the available plastic hinge rotation is required. This is a function of the ductility factor μ_θ (Vayas *et al.*, 1994) in terms of rotations according to the expression (av=available):

$$\mathrm{av}\theta_{pl} = \theta_u - \theta_p = (\mu_\theta - 1)\theta_p = (\mu_\theta - 1)\frac{M_p}{6EI}l \tag{4}$$

Using a value $\mu_\theta = 6.9$ the following available rotation has been used:

$$\mathrm{av}\theta_{pl} \cong 1.0\frac{M_p}{EI}l \tag{5}$$

where M_p is the plastic moment of the section, EI is the rigidity and l is the length of the member.

Syrmakezis +

IRREGULARITY INDEX K

For every structure an index K describing the uniformity degree of the excessive strength (overstrength) distributions, or of the "consumed" resistance quantity at the "critical regions" of the structure may be defined.

Namely, for every critical region i of the frame, an index λ_i is proposed (Syrmakezis, 1990):

$$\lambda_i = \frac{|S_i|}{|R_i|} \tag{6}$$

where S_i is the value of the selected as critical intensity quantity (action effect), and R_i the corresponding "resistance" quantity.

The excessive resistance quantity is defined by the ratio:

$$\rho_i = \frac{|R_i| - |S_i|}{|R_i|} = 1 - \lambda_i \tag{7}$$

The index K of the complete structure is proposed to be the statistical index of variance of the individual ratios ρ_i according to:

$$K = \frac{1}{N}\sum_i^N \rho_i^2 \tag{8}$$

It is noted that the value of index K always ranges between 1 and 0.

For the case of building frames all member sections around the nodes were selected as "critical regions". The "intensity" and "resistance" quantities were selected as following:

S_i = plastic rotation at critical sections

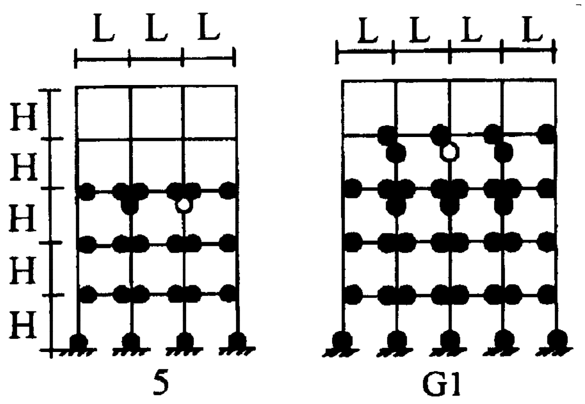
R_i = available plastic rotation at the critical sections.

Accordingly, equation 8 can be used with:

$$\rho_i == 1 - \frac{\theta_{pl,i}}{av\theta_{pl,i}} \tag{9}$$

PARAMETRIC INVESTIGATION

The methodology described above has been applied to several types of frames. Part of the results is presented in this paper. A five storey-three bay frame (referred as "5") was used as the basic structure for the examination of the influence of strength, mass and stiffness variations and a five storey-four bay frame (referred as "G1") was used for the study of the influence of geometric configuration of the frame. On Fig. 2, the geometry of the frames, as well as the positions of plastic hinges are depicted.



5 G1

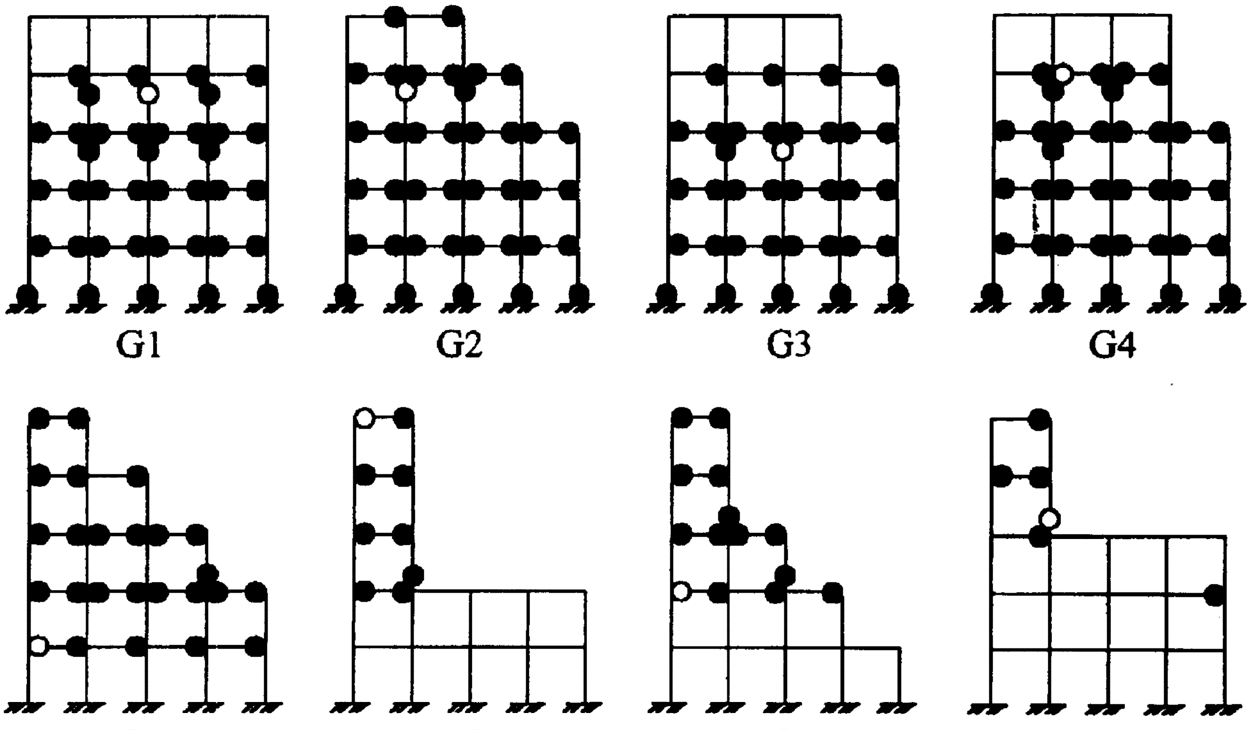
FRAME	L (m)	H (m)	COLUMNS	BEAMS
5	4	3	IPE360	HE280B
G1	4	4	IPE360	HE280B

● Plastic hinge
O Critical plastic hinge
f_y=277 MPa

Fig. 2. Geometry of the reference frames

GEOMETRIC DISCONTINUITIES

In order to investigate the effect of geometric discontinuities the frames of Fig. 3 have been analysed. It is to be noted, that proceeding from frame G1 to frame G8, the ductility factor μ_E is reduced, while at the same time the index K is increased (Fig. 4), showing the compatibility between the definitions of μ_E and K. In general, the higher the value of index K is, i.e. the more "irregular" is the frame, the lower is the value of the ductility factor μ_E.



G1 G2 G3 G4
G5 G6 G7 G8

Fig. 3. Geometry of the frames

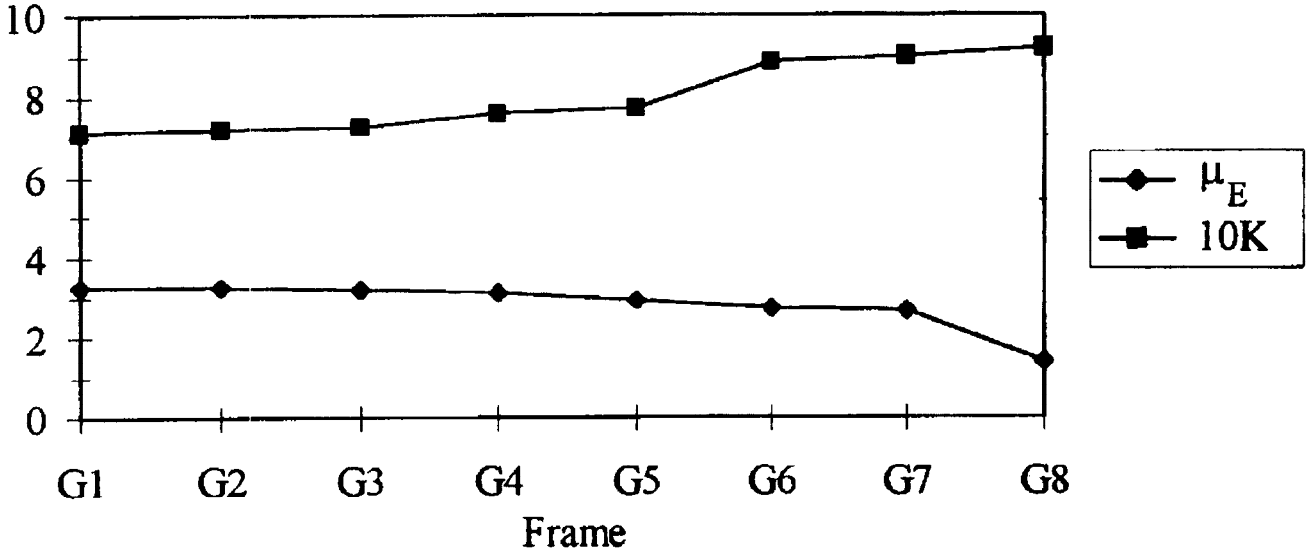


Fig 4. Influence of the geometry on the irregularity index and the ductility factor

STIFFNESS-STRENGTH-MASS VARIATIONS

Following the excisting codes, significant stiffness, strength and mass variations over the height of a building are considered as a cause of irregularity. In order to investigate the influence of these types of structural irregularities, several cases of building frames with abrupt changes in stiffness, strength and mass were examined. A part of the results referring to a 5-storey 3-bay frame is presented below. Starting from the reference frame, five different frames with 50% stiffness reduction in the columns of one storey have been studied. The frames are denoted by S1 to S5, corresponding to frames with reduced floor stiffness in the 1st, 2nd,...5th floor respectively. In the same meaning R1 to R5 refers to frames with 50% reduced floor strength, and M1 to M5 to frames with 50% increased floor mass.

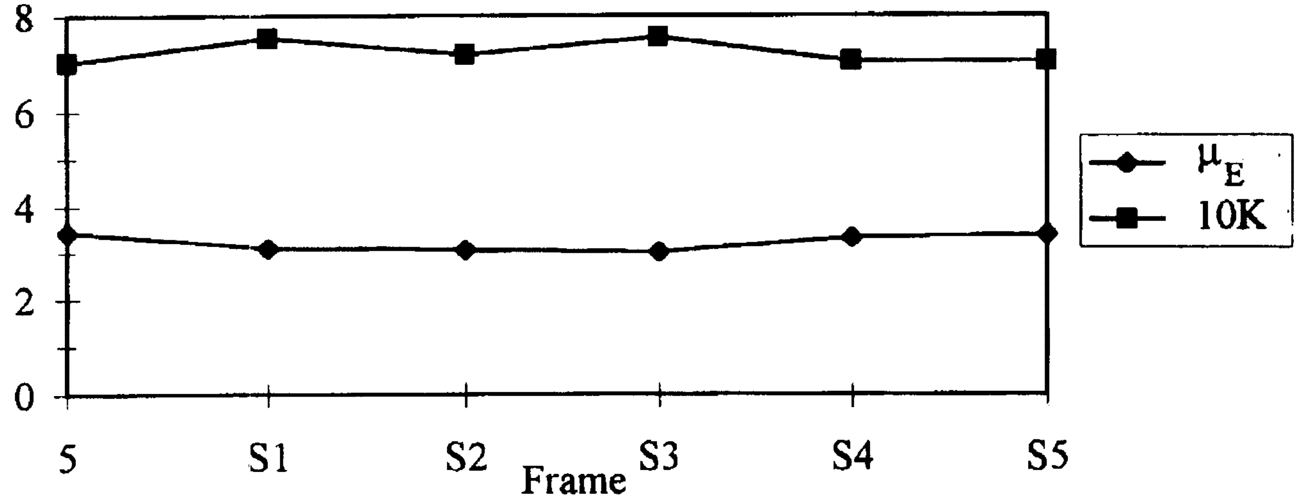


Fig. 5. Influence of stiffness reduction.

Figure 5 show the results for the different cases of stiffness variation. In spite of the significant reduction of stiffness, the general behaviour of the frames is almost unaffected. Both the ductility factor μ_E and irregularity index K are almost stable. This indicates that ductility demands are not expected to be concentrated locally, in areas of stiffness reduction.

In the cases of strength variations a higher reduction of the value of ductility factor μ_E and a corresponding higher increase of irregularity index K are observed (Fig. 6). This shows that the strength variations have to considered as reasons of irregularity.

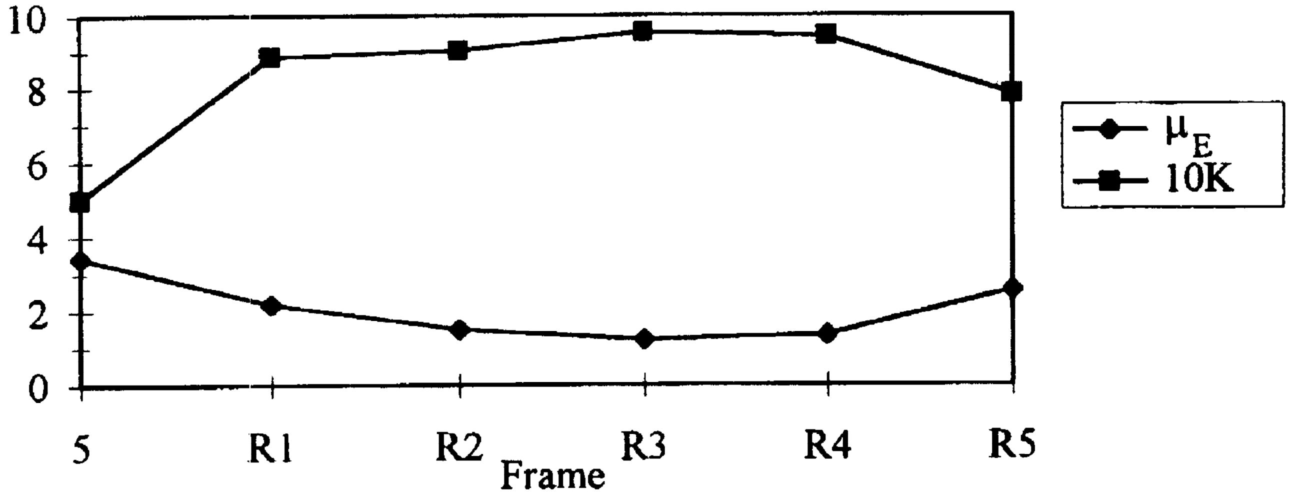


Fig. 6. Influence of strength reduction.

Finally, the behaviour of the frames is not significantly affected for the cases of mass variations. This is shown in Fig. 7 where both the ductility factor μ_E and the irregularity index K are not significantly affected.

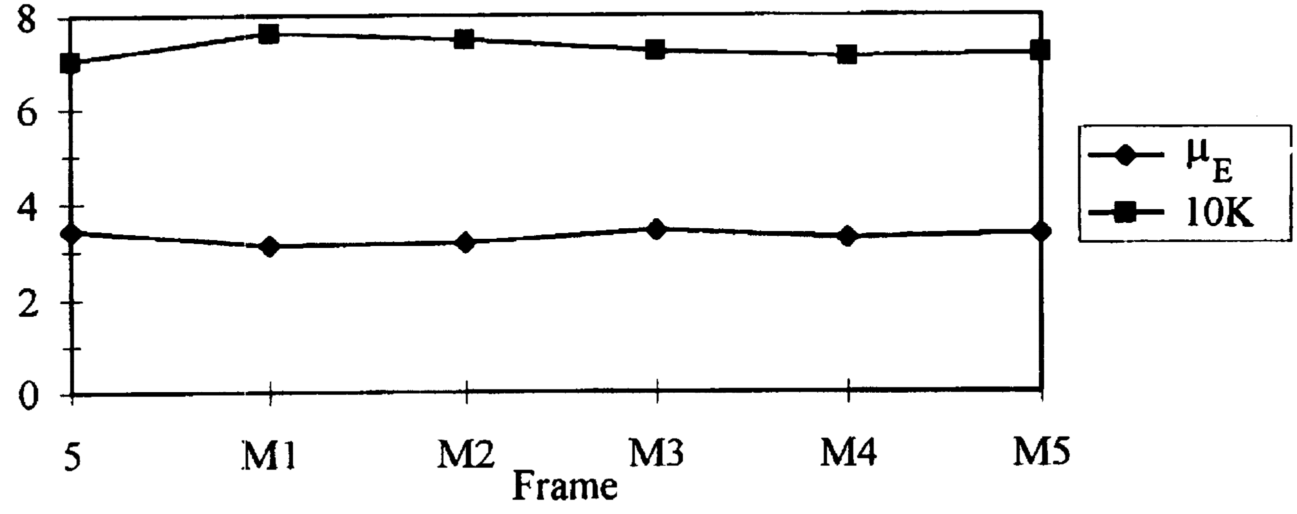


Fig. 7. Influence of mass increases.

CORRELATION OF THE INDEX K AND THE DUCTILITY FACTOR μ_E

For the correlation of the irregularity index K and ductility factor μ_E (Syrmakezis et al., 1994), values of K and μ_E are marked (Fig. 8) for the cases discussed already in figures 4,5,6,7.

Based on these plots, a straight line giving a mean correlation between K and μ_E, has been fitted. The dispersion of the various data points to the straight line are proved not significant, and allow a preliminary conclusion that a linear correlation of K and μ_E, might be possible.

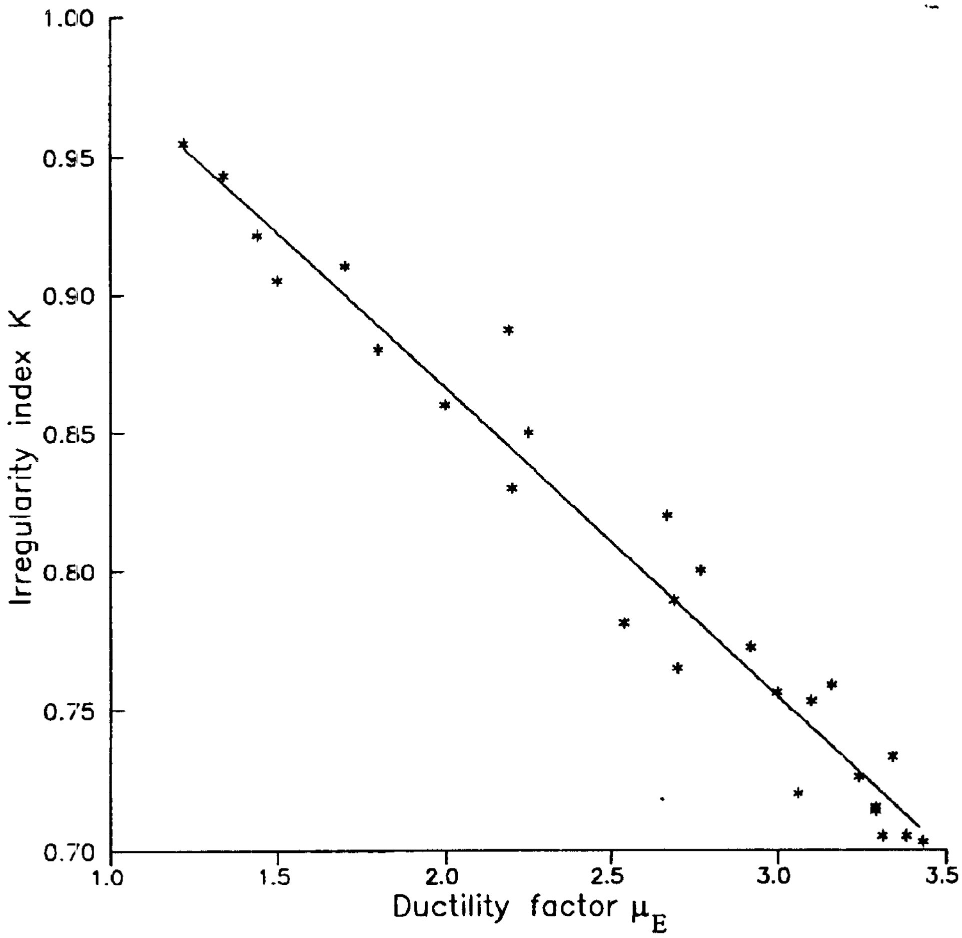


Fig. 8. Correlation of irregularity index and ductility factor.

CONCLUSIONS

This paper described through an extensive parametric study, the response of building frames to seismic loading in respect to various design parameters. An energy approach for the definition of the ductility factor μ_E has been presented. Also, for the quantitative description of the irregularity, an index K has been proposed, to be estimated through simple measurable quantities. According to the results, it has been concluded that the stiffness and mass variations over the height of the building do not affect neither the irregularity index , nor the ductility factor μ_E, and consequently they do not constitute important parameter for irregularity. Oppositely, the strength variation strongly affect the irregularity index and the ductility factor μ_E, so it has been concluded that it constitutes an important parameter for irregularity and should be treated - cautiously. The geometric discontinuities also, affect significantly the irregularity index and the ductility factor μ_E. Correlation of the irregularity index K and ductility factor μ_E has been investigated. The first results showed a possibility for such a correlation.

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