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Influence of some parameters on the inelastic earthquake response using different hysteretic models for reinforced concrete

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ABSTRACT: A series of Inelastic Earthquake Responses of single degree of freedom systems subjected to four different earthquake motions was computed,using four different hysteretic models to simulate the inelastic behavior of reinforced concrete and varying three main hysteretic parameters to study their influence and effect on the response amplitude,response waveforms,residual displacement and hysteresis shapes or energy dissipation capacity.

1 INTRODUCTION.

Many different hysteretic models have been proposed in the past trying to simulate the inelastic behavior of RC Structures, and in nowadays they are used to obtain Inelastic Earthquake Responses, but many times without understanding exactly how the hysteretic parameters of each model can influence on the response.The objectives of this paper is to analize the influence and the effect of some hysteretic parameters on the Inelastic Earthquake Response of Reinforced Concrete SDOF systems using different hysteretic models. This Response is mainly related with the Energy dissipation capacity of each hysteretic model,so all the parameters to be studied here are those which can influence on the shape(fatness and longness) of a hysteresis loop.

The models studied here are limited to those which were developed to represent the flexural behavior of reinforced concrete.So four different hysteretic models are studied and they are:
1)Degrading Bilineal. 2)Clough Model.
3)Degrading Trilineal. 4)Takeda Model.

And the hysteretic parameters studied are:
1)Post-Yielding Stiffness Parameter. B.
2)Unloading Stiffness Degradation Parameter. USDP.
3)Force Yield Relation Parameter. FYRP.

2 HYSTERETIC MODELS.

The Hysteretic models could be divided according the primary or backbone curve.In this study we use: 1) Bilinear Models (Bilinear Degrading and Clough modified model) and 2) Trilinear Models (Trilinear Degrading and Takeda).

A good hysteretic model must be able to represent the real hysteretic cyclic behavior of reinforced concrete systems , so it can provide the stiffness and resistance under any displacement hystory.The following characteristics must be in mind when it is developing analytical hysteretic models: a)Reality. b)Accuracy.c)Simplicity. and 4)Consistency. The different Hysteretic models are briefly described ahead.

2.1 Degrading Bilinear Model

It was developed from the perfectly elasto-plastic model when was added a finite positive slope to the stiffness after yielding recognizing the strain hardening characteristics of the steel in reinforced concrete.This model (see Fig. 1-I) also recognize the stiffness degradation in the behavior of the reinforced concrete as follows:

$$Kr = Ky\ (Dm/Dy)^{-\alpha} \qquad (1)$$

where:
Kr = Loading and Unloading Stiffness.
Ky = Initial Elastic Stiffness.
Dm = Previous Maximum Displacement in any direction.
Dy = Yielding Displacement.
α = Unloading Stiffness Degradation Parameter USDP.

2.2 Clough Model.

The original version of this model (Clough and Johnston 1966) keep the unloading stiffness equal to the initial elastic stiffness and the response point moves toward a maximum response point in the direction of loading simulating the

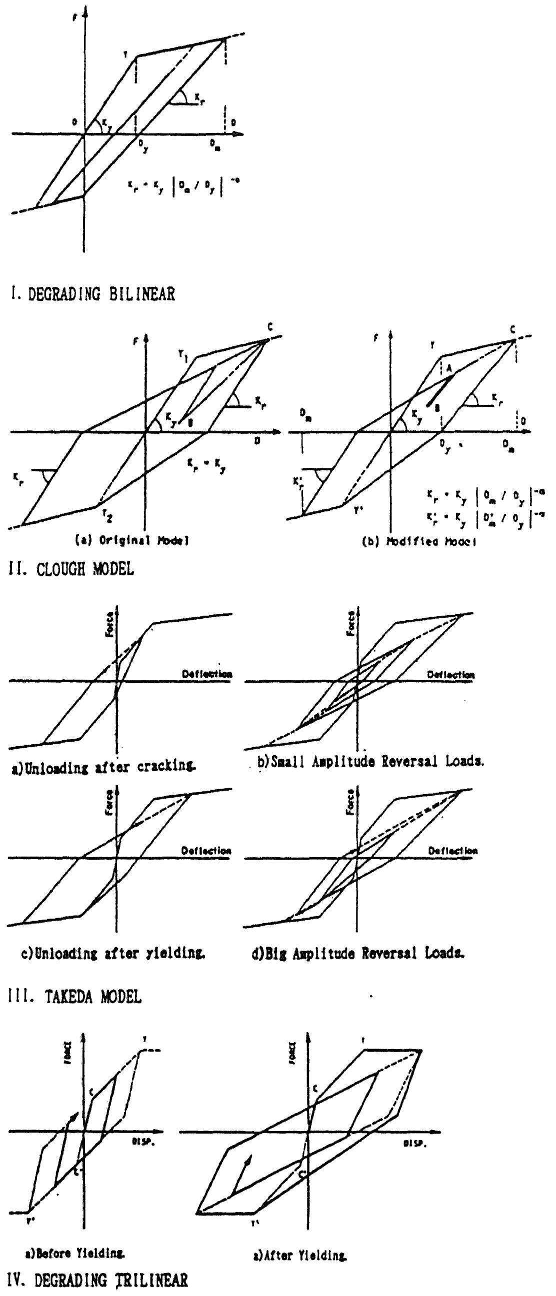

Fig. 1 Nonlinear Hysteretic Models.

stiffness degradation.This model have a small deficiency when the reloading occurs (Fig. 1-II (a)) and it was added some modification by Otani trying to get more realistic behavior during reloading.Also in this modified Clough model was incorporated a reduction in the unloading Stiffness Kr obeying the same equation (1).The modified model is used in this paper.

2.3 Takeda Model.

It is one of the more refined and sophisticated Hysteretic model (Fig. 1-III), It was developed by Takeda,Sozen and Nielsen in 1970. This model is based on experimental observations and it includes stiffness changes at flexural cracking and yielding points and also strain hardening characteristics. The main difference with the other models is that it has Hysteresis rules for inner Hysteresis loops inside the outer loop and also it has unloading stiffness degradation as follows:

$$Kr = \frac{(Fc + Fy)}{(Dc + Dy)}(Dm/Dy)^{-\alpha} \qquad (2)$$

where:
Kr = Unloading Stiffness.
Fc = Cracking Resistance Force.
Fy = Yielding Resistance Force.
Dc = Cracking Displacement.
Dy = Yielding Displacement.
Dm = Previous Maximum Displacement.
α = Unloading Stiffness Degradation Parameter USDP.

2.4 Degrading Trilinear Model.

This models has changes of Stiffness at cracking and Yielding points (Fig. 1-IV),it was originally developed by Fukada in 1969 and behaves exactly the same as Bilinear until the response reach the Yielding point, after which the model follows the strain hardening characteristics. After unloading occurs,the unloading point is considered as a new yield point in this direction.The unloading stiffnesses corresponding to pre and post cracking are reduced proportionally so that the model behaves in a bilinear type between the positive and negative yield points.

3. PARAMETERS TO BE INVESTIGATED.

The parameters studied here are relations based on the Fig. 2 and they are the followings:

3.1 POST-YIELD STIFFNESS PARAMETER(B).

This parameter is related phisically with the strain hardening phenomena of the reinforcing bars, which permit to have a finite positive stiffness after yielding and is defined as:the relation between the Ultimate Stiffness Ku and Yielding Stiffness Ky:

$$B = Ku / Ky \qquad (3)$$

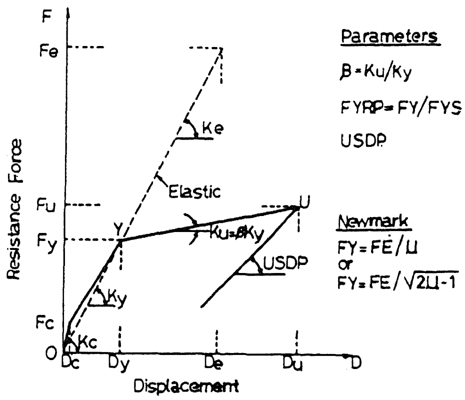

Fig. 2 Hysteretic Properties of SDOF Systems.

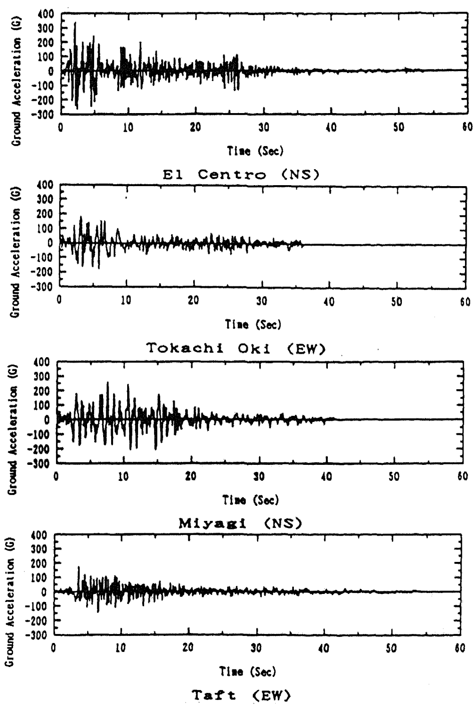

Fig. 3 Ground Motions.

3.2 UNLOADING STIFFNESS DEGRADATION PARAMETER (USDP).

This parameter try to represent the degradation or deterioration of Stiffness.This degradation is phisically related with the following phenomenas which can produce it: a)Bauschinger effect of the steel. b)Cracking in the concrete. c)Bond deterioration of the steel concrete interface. d)Slip or loss of effective anchorage. e)Shear deformation and Shear cracking.
The Hysteretic models studied here don't include all of these phenomenas,but some of them are somehow included when they use a USDP parameter as a Hysteretic characteristic of the model.

3.3 FORCE YIELD RELATION PARAMETER (FYRP).

This parameter is related with the Resistance Force Yield Level and is defined in this study as: the relation between the Yielding Force Fy at any value of ductility and the Yielding Force corresponding a ductility equal 4.0, Fys.

$$FYRP = Fy / Fys \qquad (4)$$

4. METHOD OF ANALYSIS.

Non-linear response analysis of SDOF- R.C. systems with different periods in a range between 0.2 and 1.2 secs were performed for four ground motions using four different hysteretic models (Degrading Bilinear,Clough modified,Degrading Trilinear and Takeda) and varying three hysteretic parameters :Post-Yield Stiffness Parameter B, Unloading Stiffness Degradation Parameter USDP and Force Yield Relation Parameter FYRP which mainly affect the shape of the hysteresis loop.
The ground motions considered in this analysis are:

a)El Centro,NS component,the total duration of the recorded accelerogram is 53.73 secs.The maximum acceleration is 341.70 cm/sec2.

b)Tokachi-Oki,EW component,the total duration of the recorded accelerogram is 35.99 secs The maximum acceleration is 182.90 cm/sec2.

c)Miyagi-Ken,NS component,the total duration of the recorded accelerogram is 40.94 secs.The maximum acceleration is 258.23 cm/sec2.

d)Taft,EW component,the total duration of the recorded accelerogram is 54.38 secs.The maximum acceleration is 175.95 cm/sec2.

The ground motions accelerograms used in this study are shown in Fig. 3

5. RESULTS OF ANALYSIS.

The results were compared in terms of the effect and influence of these three hysteretic parameters in different kinds of responses such as: Maximum Response Amplitude,Response Waveforms,Residual Displacement and Hysteresis Shapes or Energy Dissipation Capacity.The results are discussed for each Hysteretic Parameter analized.

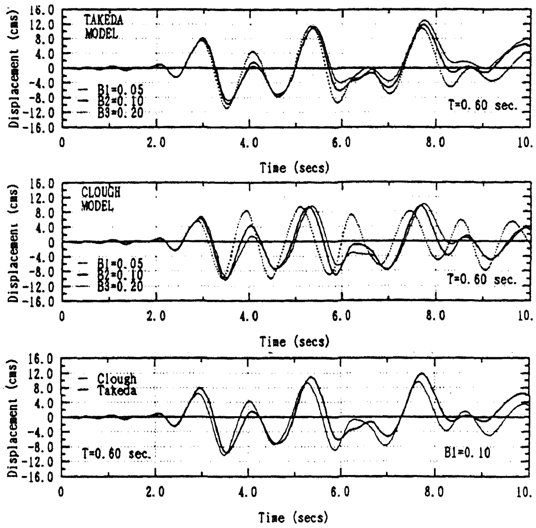

Fig. 4 Response Waveforms for Tokach-Oki EW.

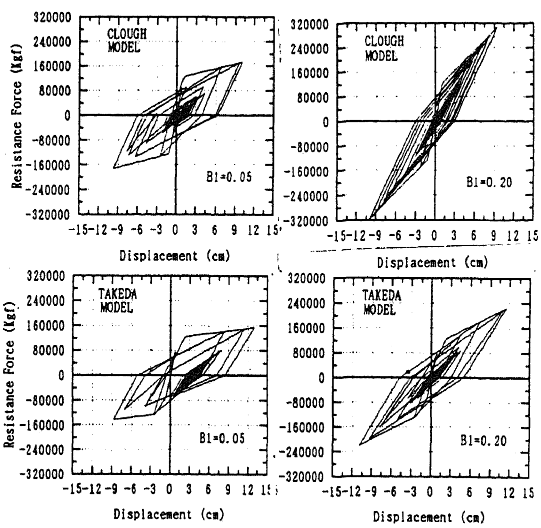

Fig. 5 Hysteresis Shapes for Tokachi-Oki EW.

5.1 POST-YIELD STIFFNESS PARAMETER(B).

Beta was varied from 0.05 to 0.20,which is considered the range in which it affect more the response.From the Analysis we can say that: The maximum Response increases for all the Hysteretic models when we decrease the value of Beta because the Hysteretic Energy Dissipation Capacity is lower.The increasing of these response is bigger for short period systems(Less than T=0.4 secs) than for long period systems.Almost all the Hysteretic models except Degrading Bilinear model shown very low influence on the response by the change of the value of Beta,but aniway Takeda model seems to be the most unaffected one.The influence of Beta is more important when we increase the value of U for the Design Criteria.The Response Waveforms(see Fig. 4) were also analized and we can see that:For a large value of Beta the Response Waveforms seems more stable,because the peak amplitudes in positive and negative directions are comparable.For smaller values of Beta(B=0.05 or Less) the Response Waveforms shown large amplitudes just in one direction producing large residual displacement on the systems.The Clough and Takeda models can give very similar Response Waveforms if it is used the same value of Beta. The Hysteresis Shapes shown very big differences for different values of Beta,these are mainly due that the Ultimate Force,which is one of the parameters to define the backbone curve is related directly with Beta.It is possible to obtain similar Hysteretic Shapes with Clough and Takeda if it is used the same value of Beta(see Fig. 5).

5.2 UNLOADING STIFFNESS DEGRADATION PARAMETER (USDP).

USDP was varied from 0.10 to 0.60 which is a normal range used on the practice for Reinforced Concrete.Fig. 6 shows the variation of the Maximum Response of three different Hysteretic models,subjected to Tokachi-Oki EW ground motion After analized these results,we have:The Maximum Response increase for all the Hysteretic models when we increase the value of USDP because the Hysteretic Energy Dissipation Capacity(Area under the Hysteresis)decrease.As same as in the case of Beta Parameter,the increasing of these responses is more important for short period systems(Less than T=0.4 secs) than for long period systems.All the Hysteretic models shown to be very influenced on the Response by this parameter,but Takeda didn't shown many changes for long period systems (greater than T=1.0 secs).Also for this parameter can be notice that it affect more the Response when the value of U for the Design Criteria is increased.The effect of this parameter on the Response Waveforms and Hysteresis Shapes shown that: For small values of this parameter (USDP=0.1 or Less) the Response Waveforms shown a peak amplitude in just one direction and it means that the system can not recover well elastically producing large residual displacement. Clough and Takeda models are not so affected on the Response Waveforms like Degrading Bilinear model is.Using the same value of USDP for the four Hysteretic models,the Response Waveforms obtained with Clough and Takeda again have the best agreement.The USDP have

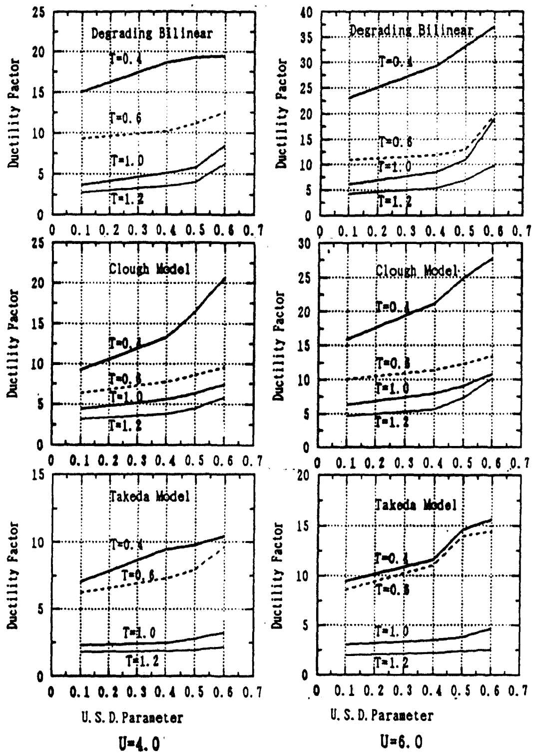

Fig. 6 Variation of the Maximum Inelastic Response with USDP for Tokachi-Oki EW

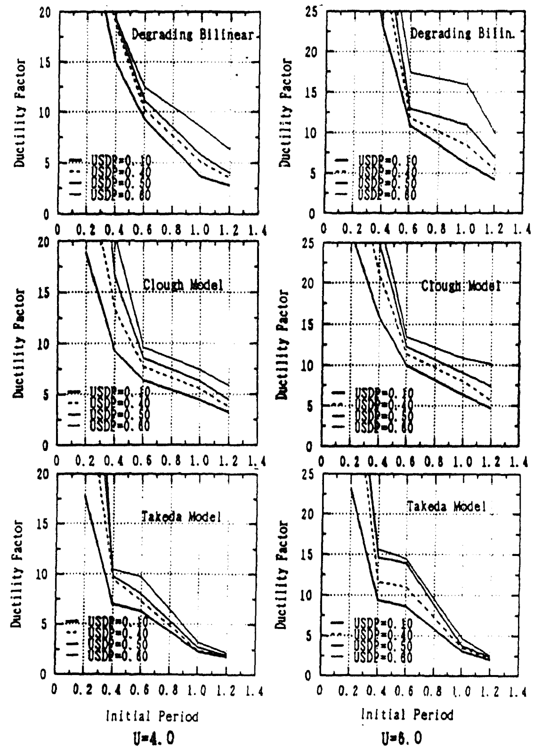

Fig. 7 Comparison of the Maximum Inelastic Response for different values of USDP and Periods for Tokachi-Oki EW.

a very big influence on the Hysteresis Shape for all the Hysteretic models.A small value of USDP means not so much degradation and the system still have good Energy Dissipation Capacity,so for that it is obtained Fat Hysteresis Shapes.Similar explanation is available for Thin Hysteresis Shapes.The influence of USDP on the Hysteresis shape seems to be lower than the influence of Beta parameter.In Fig. 7 it is shown the variation of the Maximum Inelastic Earthquake Response with different values of USDP for Tokachi-Oki EW.The following can be observed: The effect of USDP parameter on the Maximum Response is stronger than the effect of Beta parameter for all the periods analized.The Response obtained using a value of USDP=0.40 could be considered like an average between the different values of USDP normaly used for Reinforced Concrete.

5.3 FORCE YIELD RELATION PARAMETER (FYRP).

FYRP was varied from 0.6 to 1.5,so more common cases of underdesign and overdesign are cover.The variation of the Maximum Response using Degrading Trilinear,Clough and Takeda

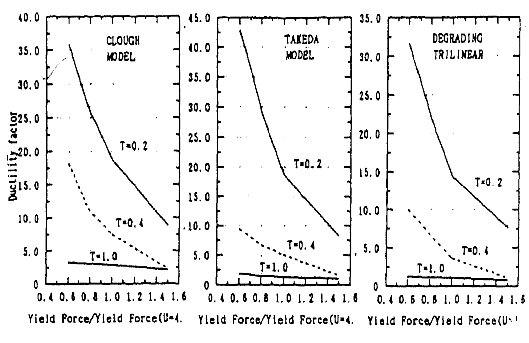

Fig. 8 Influence of FYRP on the Maximum Inelastic Response for Miyagi-Ken NS.

models for different periods and for Miyagi-Ken NS are shown in Fig. 8.From the Analysis we have that: The Maximum Ductility factor obtained increases drastically for all the Hysteretic models when we decrease the value of FYRP parameter specially for short period systems(T=0.4 secs or Less).For long period systems(T=1.0 secs or greater) the influence of FYRP is not so important and in this case Takeda and Degrading Trilinear

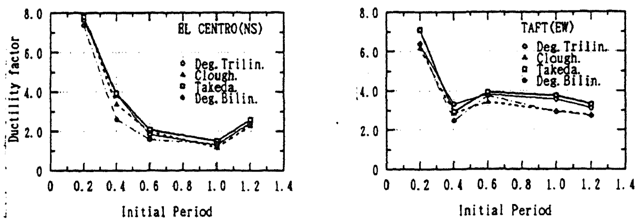

Fig. 9 Ductility Factors obtained using different Hysteretic Models and for different Earthquakes.

shown to be less affected than Clough.The control of this parameter on the Design is very important,because just taking 80% of the Yielding Force Resistance for U=4.0 as Yielding Design Force the Ductility factor obtained is around 50% bigger.

Analizing the Response Waveforms for different values of FYRP for the four Hysteretic models we can see that: For a small value of FYRP(0.70 or Less) the Response Waveforms obtained with all Hysteretic models shown large residual displacement,but the most affected model by this parameter is Degrading Bilinear.The Response Waveforms obtained with Clough and Takeda model shows the best agreement.In the same way analizing the very different Hysteresis shapes obtained using values of FYRP=0.70 and 1.30 we can distinguish between Fat Hysteresis(0.70) and Thin Hysteresis(1.30).From the comparison between all the four hysteretic models,Clough and Takeda models shown very similar hysteresis shapes for both cases of FYRP.

6. COMPARISON ON THE MAXIMUM RESPONSES FOR THE DIFFERENT MODELS.

For the comparison of the Responses dealing in terms of Maximum Response Amplitude, in this paper the ductilty factor is defined as the relation between the Maximum Displacement and Yielding Displacement for each model.In Fig. 9, we can see the ductility factors obtained using the four different models,for two different ground motions and using the same values for the hysteretic parameters to define each hysteretic model.In this case we fixed Beta=0.10,USDP=0.40 and FYRP=1.0

From this we can observe that the Maximum Response Amplitude is not so affected for the different rules of each hysteretic model,but it is more affected for the basic parameters of the hysteresis loops.Then using same values of hysteretic parameters we can have similar Responses Amplitudes using any of these hysteretic models with exception of Degrading Bilinear which reduce so much the Response Amplitude due the big Energy Dissipation Capacity of this model.But we can not say the same for Response Waveforms and for Hysteresis Shapes,because they have considerable differences for different models.

7. CONCLUSIONS.

From the results obtained in this study that have been summarized in this paper,the following conclusions can made:

a)The Hysteretic parameters which mainly affect the shape (Fatness and Longness) of the hysteresis loop (Energy Dissipation Capacity) and have more important influence on the Inelastic Earthquake Response of Reinforced Concrete SDOF systems are:Post-Yield Stiffness(B), Unloading Stiffness Degradation Parameter (USDP) and Force Yielding Relation Parameter (FYRP) for all the Hysteretic models analized.

b)The Post-Yield Stiffness Parameter(B),has medium influence on the Maximum Response Amplitude in short period range,but very small in Long period range.The effect of this parameter in Response Waveforms and Hysteresis Shapes is very important.It is purpose a value of B=0.10 as a minimum to use.

c)The Unloading Stiffness Degradation Parameter USDP,has strong influence on the Maximum Response Amplitude,Response Waveforms and Hysteresis Shapes,specially in short period systems range.It is purpose a value of USDP=0.40 as a minimum to avoid problems on Response Waveforms with large residual displacements.

d)The Force Yield Relation Parameter FYRP,has the biggest influence on the Maximum Response Amplitude for short period systems and also in Response Waveforms and Hysteresis Shapes.The value of FYRP needs to be very well controled when the design is made and never use values of FYRP less than 0.9.

e)The Takeda models seems to be the most stable model to the effect of the change of these three main hysteretic parameters.

f)Using tha same value of Hysteretic parameters for the four different hysteretic models,we can obtain very similar Response Amplitudes,but just Clough modified and Takeda models shown very good agreement between them on Response Waveforms and Hysteresis Shapes.

g)Finally if it is possible to be sure that the system will enter in the Inelastic range is enough to use a Modified Clough Model to analize it,but if not is better to use a Takeda Model.

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