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Behavior of a multi storied building exposed to fatigue loading

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Abstract –

This paper illustrates the behavior of a reinforced concrete member when subjected to cyclic loading. Experiments were conducted on steel specimens acquiring a tensile strength of 550N/mm2 with both the loading patterns of low as well as high cycle fatigue .And the cycles at the point of failure were recorded with the given load and frequency conditions. Behavior of multi storied building was studied by exposing them to the fatigue loads using time history analysis. A software analysis using ETABS – 18 was done to analyze the structure and study the behavior of reinforced concrete members under various fatigue conditions and redesigned to withstand the load applications.

To analyze the stability of a building, study was conducted on different parameters viz; drift base shear and displacement. This was done in two conditions. In first condition without any shear wall, responses were recorded. In the second condition with shear wall responses were recorded.

Key words: Time history analysis, shear wall, drift, displacement and base shear.

Introduction:

The concepts of the fatigue loading identify the changes that are observed in the material which have been identified as per the influence of stress. The concepts of the fatigue loading are identified mostly in the case of cyclic loading. This are generally represented with the help of the plotting a stress cycle curve otherwise known as the S-N curve. In this case, S identifies the stress while N identifies the number of cycles that are subjected to the failure.

Introduction to fatigue loading

The concept of the fatigue loading is quite interesting in case of the Civil Engineering. In the words of Nadot and Denier (2017), the fatigue loading identifies the changes that have been observed in a material as a result of stress which have been developed during the cyclic loading. The fatigue loading are generally represented in the form of a S-N curve

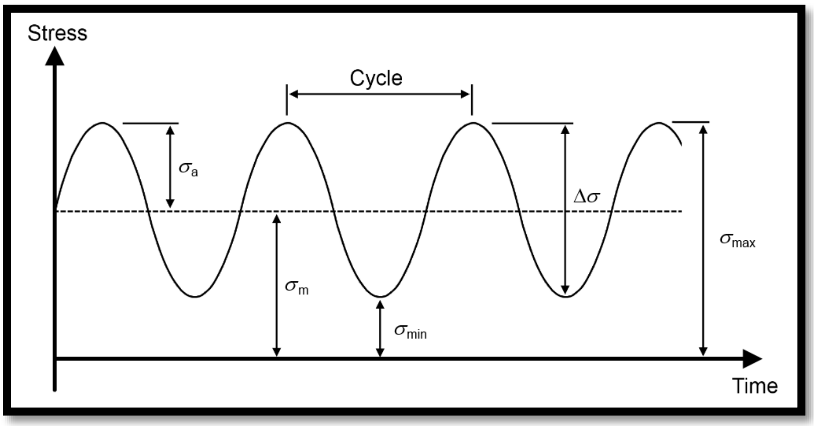

Figure 1: The S-N curve representing fatigue loading

In most of the cases, it have been identified that there is a level of progressive as well as structural damage in case of the fatigue loading. It needs to be remembered in this regard that if the local stresses are too high, these often leads to the initiation of crack. The crack grows and these finally leads to a fracture. It have also been identified that fatigue can lead to severe structural damages in the presence of a corrosive environment.

Conditions for the fatigue loading

There are two types of conditions that lead to fatigue loading. These are the Isothermal Fatigue conditions and the un- isothermal conditions.

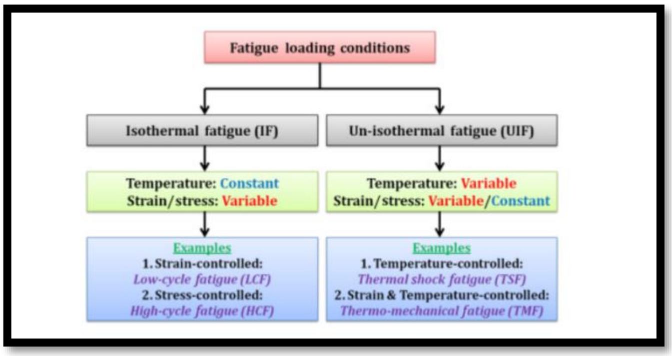

Figure 2 : The conditions of the fatigue loading

Time History Analysis

The concepts of the Time History Analysis refers to the process of the Step-by step analysis pertaining to the dynamic response with respect to a specific loading at a given instance of time. These concepts are greatly useful in determining the seismic responses with references to the dynamic loading in case of an earthquake. In the words of Dowling (2017), the time history analysis are a must for any of the multistoried buildings present in the seismic areas. These are often useful in analyzing the seismic behavior of the buildings as well as those of the place. These are often useful in developing an effective relationship among the responses as well as the earthquake intensities of the place.

The time history analysis is also otherwise known as the non-linear dynamic analysis. AS put forward by Dowling (2017), this is an important technique for conducting the structural seismic analysis, particularly in the cases when there are non linear structural responses. In this case also, it have been mentioned in the above segments that the building is in zone 2 , hence conducting the time –history analysis are useful in determining the seismic loading that these buildings are subjected to.

The Time history analyses that are conducted are of two distinct types and these are the linear time history analysis and the non linear time history analysis. In most of the cases, the Time History Analysis is conducted with the help of Etabs,

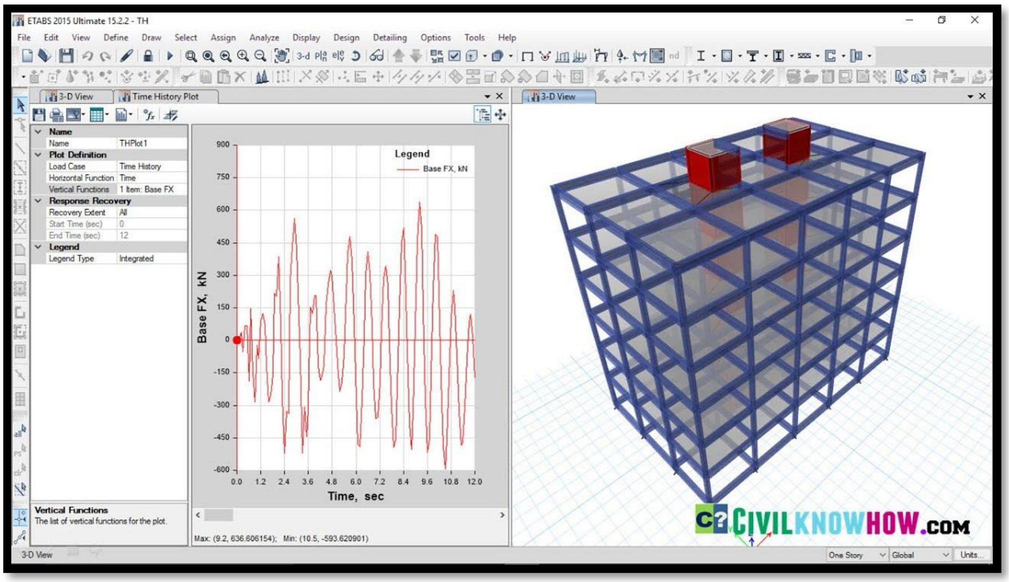

Figure 3 : A sample Time History Analysis using the E-tabs software

Base Shear

When the discussions are being made regarding the shear wall and the corresponding shear and the lateral forces, the concepts of the base shear are something that deserves a special mention in the list. The base shear identifies an overall estimate of the maximum expected lateral force that a structure can withstand from the seismic activities (Kotsovos, 2019). The concepts of the base shear can be calculated easily with the help of the formulas related to the soil material, building code and the other lateral force equations.

The Base Shear is represented with V and these are some of the following physical factors and these

- Geological Faults – the proximity of the site to the seismic sites
- The probability of the seismic ground motion

- Natural vibration of the structure
- Ductility Level as well as the over-strength of the various structural configurations
- Total weight of the structure
- The load combinations of the buildings

AISC Code	ASCE Code	ACI Code	International Building Code (NJ Edition)
1.4D	1.4D	1.4(D+F)	1.4(D+F)
1.2D+1.6L+0.5(Lr or S or R)	1.2D+1.6L+0.5(Lr or S or R)	1.4(D+F+T)+1.6(L+H)+0.5(Lr or S or R)	1.2(D+F+T)+1.6(L+H)+0.5(L or S or R)
1.2D+1.6(Lr or S or R)+(0.5L or 0.8W)	1.2D+1.6(Lr or S or R)+(L+0.5W)	1.2D+1.6(Lr or S or R)+(1.0L or 0.8W)	1.2D+1.6(Lr or S or R)+(f1L or 0.8W)
1.2D+1.6W+0.5L+0.5(Lr or S or R)	1.2D+1.0W+L+0.5(Lr or S or R)	1.2D+1.6W+1.0L+0.5(Lr or S or R)	1.2D+1.6W+f1L+0.5(Lr or S or R)
1.2D±1.0E+0.5L+0.2S	1.2D+1.0E+L+0.2S	1.2D+1.0E+1.0L+0.2S	1.2D+1.0E+f1L+f2S
0.9D±(1.6W or 1.0E)	0.9D+1.0W	0.9D+1.6W+1.6H	0.9D+1.6W+1.6H
	0.9D+1.0E	0.9D+1.0E+1.6H	0.9D+1.0E+1.6H

Figure 4 : The comparative study of the load combinations of different codes

The table that have been provided in the above sections provide a proper range of Shear wave velocity in case of the different buildings.

The base shear in case of the different buildings are calculated with the formula

$$V= 0.2 (W)$$

Materials and Methods:

1. Assessment of the material properties in the laboratory with testing as per the IS code

The research has concentrated on the collection of the data by considering the real life images from the laboratory. The researcher has gone to the practical field to collect the real life pictures of the models which have been included and analyzed in the segments below. Some of the special considerations have however been taken care of while collecting the data. All of the experiments have been conducted in the steel specimens which had acquired a tensile strenghth of around 550N/m2. Both of the Low as well as the High Loading cycle fatigue have also been considered in these cases. The concepts of the load and the frequency conditions have also been used and the cycles at the point of failure have also been recorded. The behavior of the multi storied buildings have also been considering by referring them to the standard building codes of IS standards.

2. Development of the Computational Model

The software E Tabs 18 have been used to develop a range of the computational models. The data that have thus been obtained have been presented in a tabular form and analysed using effective tools and techniques.

Findings

The design of multi storied concrete structure undergoes various deterioration in terms of both strength and stiffness. In such process of deterioration the effect of cyclic loading can be assessed, calculated and analyzed to observe the changes. The performances of the structural members are tested to see whether it can withstand the applied reversible loads, and also how it can be strengthened to become resistant in every worst condition. Depending on the number of loading cycles alternatively, the observed phenomenon from the experimental analysis is that high cycle fatigue is not hazardous to a structural component where as low cycle fatigue results in the severe damage of building studies also reveal that low cycle fatigue results in plastic deformation.

A thorough analysis is needed to understand the various types of damages occurring to the building up on the application of fatigue load.

To what extent the low cycle fatigue failure can be vulnerable may be assessed by studying the failed samples of steel reinforcement provided in the structural members.

Thus, the main aim of this paper is to calculate impair caused by low cycle fatigue on reinforcing steel bars using time history analysis.

Modeling of a building:

A non linear “time history analysis” was performed on a 2D finite element model. This was performed on a G+5 reinforced concrete frame building using software, ETABS -2018 finite element program from computer and structures Inc. (CSI, Detail 18.0). Thus the behavior of a structure under the fatigue loading conditions were observed and studied.

A reinforced concrete structure is created in order to resist the damaged caused due to fatigue loads . It is made resistant by introducing a diaphragm and in order to withstand any kind of destruction a structural member shear wall is also used as an important tool which is placed in certain positions. To study the response up on the given loading both the tension as well as compression members are taken into consideration.

A dynamic analysis was conducted using time history analysis as discussed earlier.

The building is considered under the following aspects

It is in the zone -2

With wind speed as 31.7m/sec

Terrain category=3

Structure class =B

Risk factor, K=1

Topography condition K3=1

Response reduction factor R=5

Importance factor =1

Site type – II

W coefficient cp=0.7

L coefficient cp=0.1

Where w-windward

L-leeward

To understand observe and study the difference and the level of damage occurring through both low cycle as well as high cycle fatigue results are attained.

Results and discussions:

- Yield point – 605.30 N/mm2
- Tensile strength -710.20 N/mm2
- Total elongation at maximum force – 7.80mm
- Relative elongation – 18.10mm
- Tensile strength / Yield strength Ratio -1.17

Properties of low cycle fatigue-

- Diameter -20mm
- Grade as per IS 1786 - Fe 550
- Load - +173 to -173 N/mm2
- Wave form – sinusoidal
- Frequency -0.35 Hz
- Cycles at failure - 12486

Properties of high cycle fatigue-

- Diameter – 20mm
- Grade as per 1786 – Fe 550
- Load – 300 MPa
- Wave form – sinusoidal
- Frequency – 200Hz
- Cycles at failure - 2064789

Samples of fatigue testing

Figure 5: Fatigue testing machine

The above figure points out towards the machine in which the fatigue testing are done. The fatigue test helps in determining the life expectancy as per the actual service loads in the real world applications. In the above diagram, a rod has been placed between the two steers on the platform and the load has been applied on them gradually. The load has been increased gradually, to check the point of fatigue of the rod. The elongation, tearing as well as the indentation tests help in ensuring the fatigue load tendency of the rod. The yield of breakage and the elongation are some of the effective factors that help in ensuring the durability of the material. The first point from where the distraught begins is usually identified as the point of yield in case of the cyclic loads.

<u>Plan of the fatigue model</u>

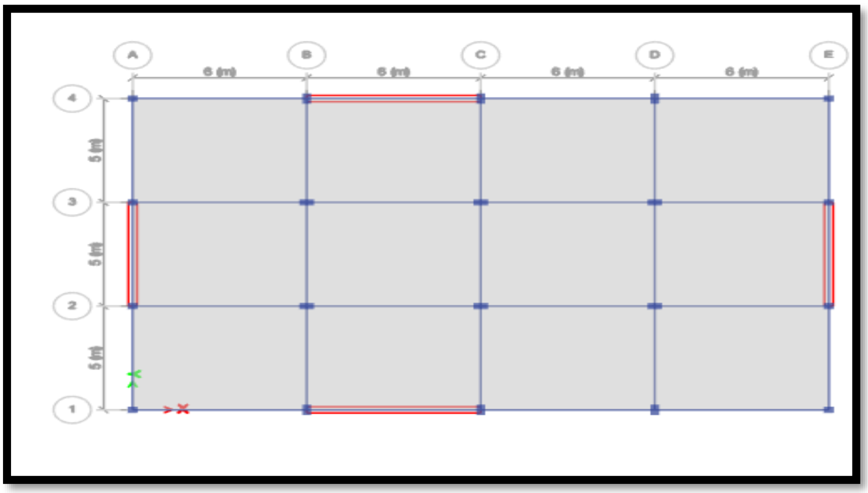

Figure 6: The fatigue plan model of the building

Sectional properties-

- Beam 230x500mm
- Column 300 x350 mm

- Column 300x 500 mm
- Plinth beam 300 x375mm
- Shear wall 300mm
- Rigid diaphragm

Results and discussions in Analysis and design:

HCF -DRIFT:

TABLE: Story Max Over Avg Drifts

Story	Output Case	Step Type	Direction	Max Drift	Avg Drift
				mm	mm
Story5	HCF y	Max	X	2.07E-09	3.43E-10
Story5	HCF-x	Max	Y	1.04E-08	6.99E-09
Story4	HCF y	Max	X	3.05E-09	2.62E-09
Story4	HCF-x	Max	X	1.34E-08	1.3E-08
Story3	HCF y	Max	X	5.06E-09	3.49E-09
Story3	HCF-x	Max	Y	6.99E-09	5.37E-09
Story2	HCF y	Max	X	0.02	0.008
Story2	HCF-x	Max	Y	0.012	0.006
Story1	HCF y	Max	Y	0.012	0.006
Story1	HCF-x	Max	Y	0.012	0.006

Table 1 : the average drifts of the load as mentioned above

The above table has tried to identify the average drifts of the various stories in case of a multi storied building. The drift of a building identifies the total lateral displacement in case of a building or the stories of the building.

Displacement hcf:

TABLE: Story Max Over Avg Displacements

Story	Output Case	Step Type	Direction	Maximum	Average
				mm	mm
Story5	HCF y	Max	X	1.18E-08	1.13E-08
Story5	HCF-x	Max	X	4.61E-08	4.57E-08
Story4	HCF y	Max	X	1.27E-08	1.2E-08
Story4	HCF-x	Max	X	5.1E-08	5.02E-08
Story3	HCF y	Max	X	1.14E-08	1.09E-08
Story3	HCF-x	Max	X	6.52E-08	6.47E-08
Story2	HCF y	Max	X	1.03E-08	9.38E-09
Story2	HCF-x	Max	X	8.67E-08	8.57E-08

Table 2: Displacement of the buildings

The above explains the table of the displacements of the building. It is known to all that the displacements occur mostly in the case of the buildings in the X direction owing to the gravitational pull and the drift of the buildings.

Base reactions:

TABLE: Base Reactions

Output Case	Case Type	Step Type	FX	FY
			kN	kN
HCF y	LinModHist	Max	8.8E-07	-0.0005
HCF-x	LinModHist	Max	-0.0007	1.32E-06

Table 3 : Base Reactions of the buildings

The above table points out towards the base reactions of the building. It can be seen that as far as the base reactions are considered, the drifts of the building have been both been on the X as well as the Y axis of the buildings. There are however some of the differences in the actions that have been recorded in either of the cases. In case of the Y axis, it have been identified at 8.8E-07 while in case of the X axis it have been identified at -.0007 only.

Low cycle fatigue:

Base reaction before:

Output Case	Case Type	FX	FY	FZ	MX	MY	MZ
		kN	kN	kN	kN-m	kN-m	kN-m
EQX	Lin-Static	-269.693	0	0	0	-3186.59	2022.701
EQY	Lin-Static	0	-258.631	0	3055.889	0	-3103.56
Comb+EX	Combination	-323.631	-93.1071	12519.86	95007.93	-154041	1309.961
Comb+EY	Combination	-97.0894	-310.357	12519.86	97574.87	-151364	-2996.1
Comb+EX1	Combination	-404.539	-116.384	11329.83	86359.91	-140711	1637.451
Comb+EY1	Combination	-121.362	-387.946	11329.83	89568.59	-137365	-3745.12
Comb+EX2	Combination	-404.539	-116.384	6797.898	52366	-86338.8	1637.451
Comb+EY2	Combination	-121.362	-387.946	6797.898	55574.69	-82992.8	-3745.12
Comb-EX	Combination	323.6313	93.1071	12519.86	92807.69	-146393	-1309.96
Comb-EY	Combination	121.3618	310.3569	12519.86	90240.74	-148783	2814.054
Comb-EX1	Combination	404.5392	116.3838	11329.83	83609.61	-131152	-1637.45
Comb-EY1	Combination	121.3618	387.9461	11329.83	80400.92	-134498	3745.121
Comb-EX2	Combination	404.5392	116.3838	6797.898	49615.7	-76779	-1637.45
Comb-EY2	Combination	121.3618	387.9461	6797.898	46407.02	-80124.9	3745.121

Table 4: LCF of the base reactions

The table above provides an idea as to the base reactions before as well as the combination of the loads that have been used with these. In case of the case type typologies, these have been identified that there are some of the combined loads that have been used in this case. The impact of these on the X, Y and Z axis have also been included and discussed in the table above.

Base reaction after:

TABLE: Base Reactions

Output Case	Case Type	FX	FY	FZ	MX	MY	MZ
		kN	kN	kN	kN-m	kN-m	kN-m
EQX	LinStatic	-301.399	0	0	0	-3559.85	2260.492
EQY	LinStatic	0	-283.269	0	3345.716	0	-3399.23
Comb+EX	Combination	-361.679	-101.977	12688.02	96364.63	-156528	1488.867
Comb+EY	Combination	-108.504	-339.923	12688.02	99175.03	-153538	-3265.3
Comb+EX1	Combination	-452.098	-127.471	11540.03	88055.78	-143820	1861.084

Comb+EY1	Combination	-135.63	-424.904	11540.03	91568.78	-140082	-4081.62
Comb+EX2	Combination	-452.098	-127.471	6924.017	53435.7	-88428	1861.084
Comb+EY2	Combination	-135.63	-424.904	6924.017	56948.7	-84690.1	-4081.62
Comb-EX	Combination	361.6787	101.9769	12688.02	93955.71	-147984	-1488.87
Comb-EY	Combination	135.6295	339.923	12688.02	91145.31	-150654	3061.855
Comb-EX1	Combination	452.0984	127.4711	11540.03	85044.64	-133141	-1861.08
Comb-EY1	Combination	135.6295	424.9038	11540.03	81531.64	-136878	4081.624
Comb-EX2	Combination	452.0984	127.4711	6924.017	50424.55	-77748.4	-1861.08
Comb-EY2	Combination	135.6295	424.9038	6924.017	46911.55	-81486.3	4081.624

Table 5 : Base Reactions for a range of combinations

The table is useful in identifying the base reactions that have been obtained from the building after it have been subjected to drifts and displacement. The loads in this case are also combinations and the impacts of these on the X, Y and Z axis have also been identified in the table above. The values that have thus been obtained are quite of the mixed types which clearly identifies the mixed effects of the load on the building. It also identifies the impact of these on each of the storey's of the building.

LCF

Displacement before:

TABLE: Story Max Over Avg Displacements

Story	**Output Case**	**Case Type**	**Step Type**	**Direction**	**Maximum**	**Average**	**Ratio**
Story5	LCF-x	LinModHist	Max	X	53.75	53.633	1.002
Story5	Comb+Lx	Combination	Max	X	64.565	64.348	1.003
Story5	Comb-Lx	Combination	Max	X	54.214	53.873	1.006
Story5	Comb+Lx1	Combination	Max	X	80.71	80.44	1.003
Story5	Comb-Ly	Combination	Max	X	16.58	16.168	1.025
Story5	Comb+Ly	Combination	Max	X	19.587	19.297	1.015
Story5	Comb-Lx1	Combination	Max	X	80.71	80.44	1.003
Story5	Comb+Ly1	Combination	Max	X	24.488	24.126	1.015
Story5	Comb-Ly1	Combination	Max	X	20.729	20.214	1.025
Story5	Comb+Lx2	Combination	Max	X	80.713	80.443	1.003
Story5	Comb-Lx2	Combination	Max	X	67.774	67.35	1.006
Story5	Comb+Ly2	Combination	Max	X	24.491	24.129	1.015
Story5	Comb-Ly2	Combination	Max	X	20.732	20.218	1.025

Table 6 : Maximum over average displacements (before)

The table explains the displacements that have happened before it was subjected to loading and the displacement and the drift conditions. These helps in finding the value of the displacements before the drift conditions.

Displacement after:

TABLE: Story Max Over Avg Displacements							
Story	**Output Case**	**Case Type**	**Step Type**	**Direction**	**Maximum**	**Average**	**Ratio**
					mm	mm	
Story5	LCF-x	LinModHist	Max	X	0.465	0.465	1
Story5	Comb+Lx	Combination	Max	X	0.538	0.537	1.002
Story5	Comb-Lx	Combination	Max	X	0.602	0.602	1.001
Story5	Comb+Lx1	Combination	Max	X	0.679	0.678	1.002
Story5	Comb-Ly	Combination	Max	X	0.181	0.179	1.014
Story5	Comb+Ly	Combination	Max	X	0.142	0.139	1.022
Story5	Comb-Lx1	Combination	Max	X	0.679	0.678	1.002
Story5	Comb+Ly1	Combination	Max	Y	1.188	1.181	1.005
Story5	Comb-Ly1	Combination	Max	X	0.234	0.23	1.014
Story5	Comb+Lx2	Combination	Max	X	0.685	0.684	1.002
Story5	Comb-Lx2	Combination	Max	X	0.766	0.765	1.001
Story5	Comb+Ly2	Combination	Max	X	0.191	0.187	1.02
Story5	Comb-Ly2	Combination	Max	X	0.24	0.236	1.014

Table 7 : Maximum over average displacements (after)

The table aims to estimate the exact values of the base aspects of the building after it have subjected to the loads. The table aims to identify the displacements in these cases.

Drift before:

TABLE: Story Max Over Avg Drifts					
Story	**Output Case**	**Case Type**	**Step Type**	**Direction**	**Max Drift**
					mm
Story5	LCF y	LinModHist	Max	Y	5.483
Story5	LCF-x	LinModHist	Max	X	5.253
Story5	Comb+Lx	Combination	Max	X	6.303
Story5	Comb-Lx	Combination	Max	X	4.898
Story5	Comb+Lx1	Combination	Max	X	7.879
Story5	Comb-Ly	Combination	Max	X	1.469
Story5	Comb+Ly	Combination	Max	X	1.891
Story5	Comb-Lx1	Combination	Max	X	7.879
Story5	Comb+Ly1	Combination	Max	X	2.364
Story5	Comb-Ly1	Combination	Max	X	1.837
Story5	Comb+Lx2	Combination	Max	X	7.879
Story5	Comb-Lx2	Combination	Max	X	6.123
Story5	Comb+Ly2	Combination	Max	X	2.364
Story5	Comb-Ly2	Combination	Max	X	1.837

Table 8 : Maximum over average drifts (before)

The table helps in identifying the maximum drifts whose values have been identified a those over average. The table clearly identifies that most of the drifts have been in the X directions. These also points out that there have been some of the sways of the building in the X direction. The Sway can be considered as dx (small variable). The direction of the Sway will be in the opposite direction of the applications of load in the building

Drift after:

TABLE: Story Max Over Avg Drifts							
Story	**Output Case**	**Case Type**	**Step Type**	**Direction**	**Max Drift**	**Avg Drift**	**Ratio**
					mm	mm	
Story5	LCF-x	LinModHist	Max	X	0.12	0.12	1
Story5	Comb+Lx	Combination	Max	X	0.137	0.137	1.002
Story5	Comb-Lx	Combination	Max	X	0.156	0.156	1.001
Story5	Comb+Lx1	Combination	Max	X	0.174	0.173	1.002
Story5	Comb-Ly	Combination	Max	X	0.047	0.046	1.014
Story5	Comb+Ly	Combination	Max	X	0.034	0.033	1.023
Story5	Comb-Lx1	Combination	Max	X	0.174	0.173	1.002
Story5	Comb+Ly1	Combination	Max	X	0.045	0.044	1.022
Story5	Comb-Ly1	Combination	Max	X	0.061	0.06	1.013
Story5	Comb+Lx2	Combination	Max	X	0.176	0.175	1.002
Story5	Comb-Lx2	Combination	Max	X	0.2	0.2	1.001
Story5	Comb+Ly2	Combination	Max	X	0.047	0.046	1.021
Story5	Comb-Ly2	Combination	Max	X	0.063	0.062	1.013

Table 9 : Maximum over average drifts (after)

The table has determined the average value of all of the drifts after it have been subjected to the loads. It helps in determining the average drifts after the loads have been applied and increased in case of the buildings.

Conclusion:

This paper has presented an overall idea as to the concepts of fatigue load as well as high and low cyclic loads. It will be useful in providing an idea as to the concepts of the fatigue loading and the ways the fatigue loading occurs in the thermo mechanically treated steel bars. It will be useful in demonstrating the concepts of sway and displacement in case of the buildings. It has also provided an idea as to the various combinations of loads and the ways the combinations of these impact the building and the sways in it.

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