The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

TIMBER HOUSE STRUCTURE WITH URUGUAYAN WOOD

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ABSTRACT:

The objective of this project is to support the promotion of the use of wood specifically eucalyptus for structural purposes in Uruguay. Therefore are able to apply in the entire line of production that may arise for the application in the housing development. The study use for the development project the international standards so that the same could be guarantee not only nationally applicability and have its appreciation in other international areas. Using updated information on the study of the mechanical properties of Uruguayan wood done through LATU (Technological Laboratory of Uruguay) and JICA (Japan International Cooperation Agency), it that was developed, applying an important background of wooden structures as it has historically Japan. With Applying a methodical system, was be reached analyze a structural model, considering a horizontal force of earthquake and thus come to identify various considerations to optimize its use in different conditions.

KEYWORDS: Structural design, Wooden structure, Uruguayan wood, Eucalyptus, Earthquake behavior

1 BACKGROUND

The idea of carry out a structural project with Uruguayan wood, started 6 years ago. After, analyze the information about Uruguayan wood, the mechanical properties data of timber in Uruguay produced by JICA - LATU. So it was that the preparation thereof, led to consider the scale of housing, in order to illustrate the potential uses and greater applicability. Therefore, for these conditions, was development the project, and it was started to apply the standards design. Many are the reasons that push to achieve the same too. The need for housing is the most important. Thus the lower cost of housing is one of the potential targets in the long term. Many are the challenges that are presented in front of it, on the one hand deeper into the whole issue of structural design in wood. Also recognize that information is very recent and therefore subject to the absence of relevant information in order to reach a conclusion with objectives.

Uruguay presents a major agricultural development and a very limited tradition forest, however, in recent years, due the state policy promotion, which started in 1989; there has been a major development forest sector, on the basis of external competitiveness and a sustainable development of production. The evolution of gender plantations (Fig 1) shows that historically, gender Eucalyptus has been the most planted.

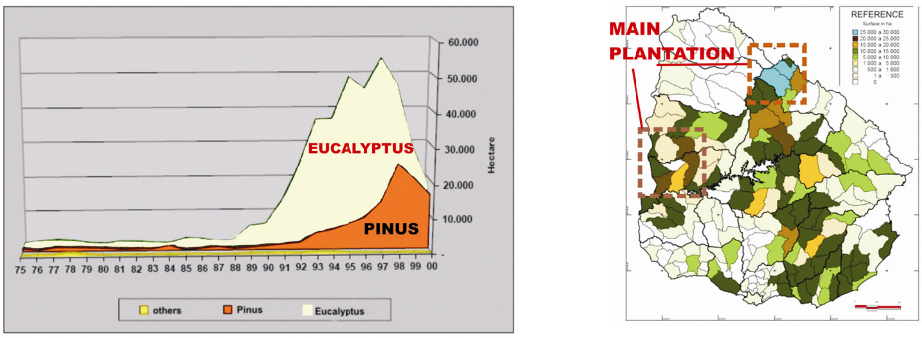


Figure 1 Evolution and Distribution of forest area

With reference to products generated, the first industries processing surveyed are: sawing (84.0%), packaging (4.5%), materials for manufacturing (1.2%) and others (10.3%). In the coming years the sawmill industry will have little processing of wood managed specifically. The large sawmills with new technology have good-sized machinery, organized in well-designed productive circuits and complete auxiliary equipment (handling logs, internal transport of products, mechanized mining waste, and so on.). The same is not true in the rest of the plant where most of used equipment is obsolete (mean age 20 to 40 years), inappropriate and inefficient to meet the basic conditions of process, compatible with the goals for the future.

2 QUALITY OF WOOD PRODUCED IN URUGUAY

In Uruguay there according to the Direction of Forestry MGAP an area under forest projected in the order of 616,000 hectares by the year 2002, this surface is occupied approximately to 25% plantations of Eucalyptus Grandis, a 19% Pines Taeda and a 7% Pines Elliottii. With the knowledge of the mechanical strength of the Uruguayan wood, can be classified and optimize the industrial process for obtaining wood suitable for structural use. The mechanical properties of timber produced in Uruguay are being studied and characterized for several years by the Forest Products Sector of LATU, with emphasis on Eucalyptus Grandis and Pines Taeda and Elliotti. The research was to conducted 12 samples (30 trees) from different regions, ages and backgrounds seed. Then was possible analyzed the variation among trees of the same stand, the change in the radius between adult and juvenile wood and also the variation in the height of 12 meters.
Based on these results was did make this structural classification of wood, were it put into practice the standard classification JAS (Japan Agriculture Standards). This rule states that all those elements of wood which exceeding category E 70 or MOE (Modulus of Elasticity) worth more than 7850 MPa are suitable for structural use in construction.

3 PROJECT DESIGN

The Uruguayan classification of house is given by m^2 of floor space and the number of bedrooms. We thus homes of 1, 2, 3 and 4 bedrooms or more. The first classification is for an area of 45 m^2 and successively adding additional 15 m^2 for the additional bedroom. This is the category I, or minimum. Category II respects the same approaches, but the basic area is larger, 60 m^2 by 1 bedroom and 15 m^2 are added for additional bedroom. Category III is for the case where the areas above are exceeded. The single bedroom should not be less than 14 m^2 his minimum side should not be less than 2.5 m and 2.40 m minimum height. All services must be considered in housing and must have a minimum comfort, natural conditioning, conditioning electric, conditioning sanitary, and conditioning acoustic.
It is a design so exemplifies a prototype, as a model, a simulated area, to have a volume of housing closer to the needs, in accordance with the housing program today prevailing in Uruguay. In all moment, the quality of the spaces, the conditions of habitability, and good natural illumination was priority. On the other hand the image, like designed how was the opening to exterior spaces.
The system of industrial timber cutting in Uruguay used British units, "inches" and "foot". For this reason standard cutting unit uses half foot or foot, to define sections and tables cost. The importance of this application lies in that anywhere in the country we can find these sections without prior consultation or reservation. Also, this industrial dimension is used for cutting across South America by most countries. This is one of the reasons for which this research project is important to a greater or lesser scale. Another formal aspect in the formal development of the project is the consideration of using only sections of 1 "x 6", 2 "x 6", 2 "x 12" and 5” x 5” inches.
This consideration and the fact that they are the most popular sections in the region, make this model a first approximation to use very viable, in order to assess their applicability in structural applications in future projects.
The idea of this research project started in Uruguay, in relation with the evolution of wooden production, and the possibility of constructions applying different methods. In this sense, this research about develop a wooden house structure includes many aspects like Japanese Timber Frame Structure and Wood-Frame construction from North America (see Fig 2).

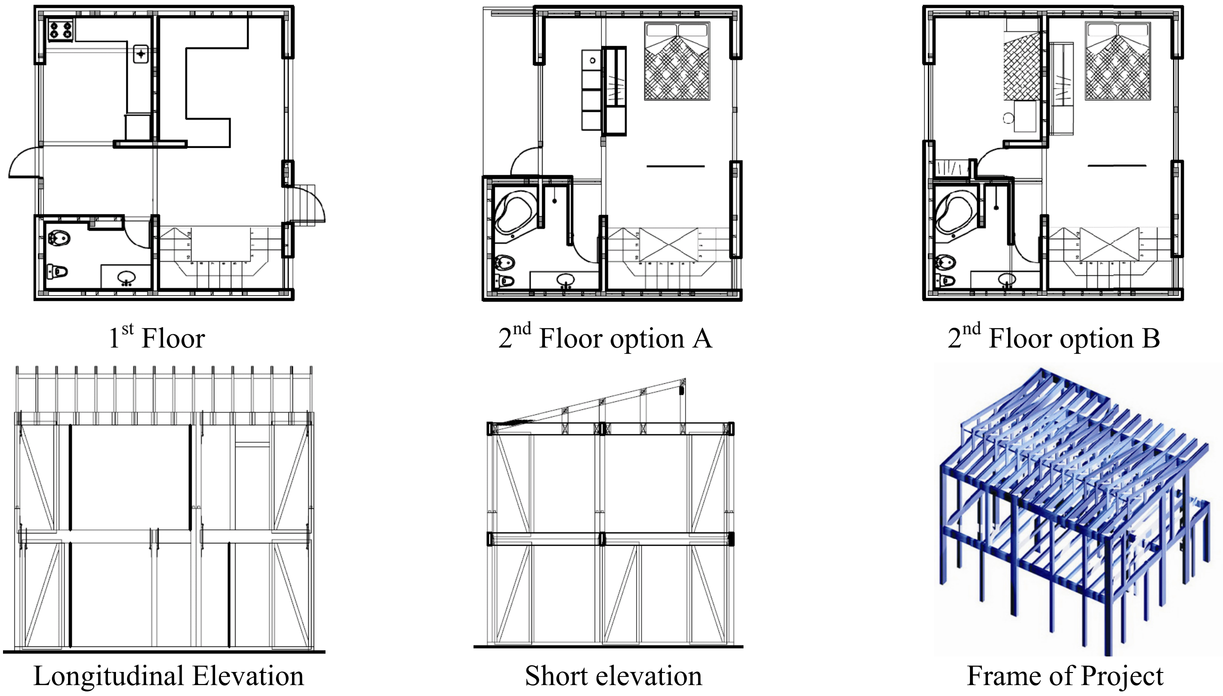


Figure 2 Plans of project and Frame model

4 STRUCTURAL DESIGN

4.1 Allowable stress of Uruguayan wood

The data of bending test about Uruguayan wood is shown in Table 1. It's possible to see the allowable stress of Uruguayan wood, applying the Normal distribution. Normal distribution is the most widely used family of distributions in statistics and many statistical tests are based on the assumption of normality (see eq. 4.1). In probability theory, normal distributions arise as the limiting distributions of several continuous and discrete families of distributions.

Thus, to estimate the value of Fb, apply the equivalent value to 5%, in the criterion of normal distribution. Thus, for a value of 5%, the value of Z = -1.64545 (see eq. 4.2) and applying the pattern before submitted, to a value of AVE = μ = 83.2 N/mm^2 and value of σ = SD = 10.2, getting a value of X = Fb = 66.42 N/mm^2 (see Table 2).

$$\Phi(x) = \Phi_{0,1}(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{u^2}{2}\right) du \tag{4.1}$$

$$Z = \frac{X - \mu}{\sigma} \tag{4.2}$$

In this value is that applied the following pattern, fb = 1.1 / 3 x Fb. Then it is got the value of permissible force to be applied in the project and thus able to verify the strength of the members.

Table 1 Bending test data of Uruguayan wood

	Small pieces free defects		**Specimen (real size)**	
	MOE(Mpa)	**MOR(Mpa)**	**MOE(Mpa)**	**MOR(Mpa)**
Number	203	203	203	203
AVE	**11766**	**83,2**	**11607**	**50,6**
Max	17069	116,3	18484	76,2
Min	8978	61	7076	17,7
SD	1414	10,2	1664	13,9
CV(%)	12	12,3	14,3	27,5

Table 2 Allowable stress

Bending Test	Standard Strength Fb N/mm^2	Allowable Bending fb N/mm^2	Allowable Shear fs N/mm^2	Allowable Compressive fc N/mm^2
Eucalyptus Grandis	66,42	24,35	3,11	13,00

4.2 Load Conditions

From studies between JICA - LATU, it saw that the value of density for Eucalyptus Grandis is 0,459 g/cm^3. As such, as these values have not been approved by the Uruguayan legislation for use in construction, it was applies the value from the Uruguayan standard. These values derived from the international standards. For the type of wood, found according to Uruguayan standard values (UNIT 33-91) for Eucalyptus in generally the value use is 850 kg/m^3 and with this value was verified each member. Furthermore, in the same manner, live loads per m^2 are considered slightly lower in Uruguay. A quick comparison allow for a live load of 1500 N/m^2 in Uruguay, against 1800 N/m^2 that apply in Japan for this type of construction (housing) in general. It was subsequently proceeded to determine the weight (W_i) per m^2 surface both inside and roof surface. The Japanese code defined seismic force (Q_i) as eq. (4.3), and the coefficient C_i is seismic story shear coefficient from eq. (4.4) which is defined by the characteristics of the floor (P_i) uniform seismic coefficient, and under the full weight of the building. Being A_i (Vertical Distribution factor) relationship of the weight of the upper floor, or story that are above the level considered on the total weight of the building. The amount of force is shown in Table 3.
In the Fig. 3 and 4 is possible to observe how is the amount of floor considered in the process to determinate the respective value of W_i and Q_i respectively.

Table 3 Value of earthquake power

C1	C2	Z	Rt	A1	A2	T	h	W1	W2	a1	a2	Co	Q1	Q2
0.2	0.231	1	1	1	1.155	0.084	2.8	175830	121656	1	0.41	0.2	59497	28101

$$Qi = Ci \times \sum_i^n W_i \quad (4.3)$$

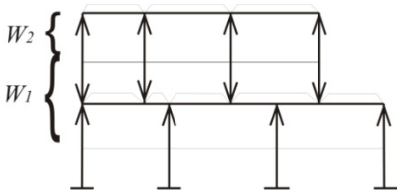


Figure 3 W_i Weight above th Ith story

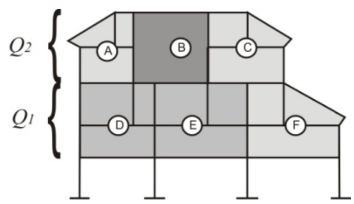


Figure 4 Q_i Shear force in the Ith for level design

$$C_i = P_i / W_i \quad (4.4)$$

$$A_i = 1 + \left(\frac{1}{\sqrt{ai}} - ai\right) {}^{2T}/_{1+3T} \quad (4.5)$$

$$P_i = Q_i - Q_{i+1} \quad (4.6)$$

4.3 Verification

4.3.1 Roof truss

The theme roof truss is an important paragraph because use the thinner and slight section. Ever since its formally conception raised, its design, without knowing what sections are to be used. An important consideration was the useful, in all its dimensions, lighting down for the winter, and a more adequate ventilation of housing for the summer.

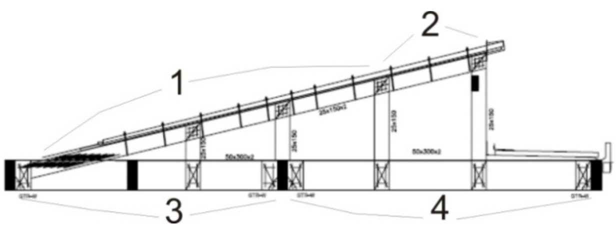


Figure 5 Truss members design

With the intention to unify the criterion, was expressed in international units (SI) and from here all. In its design, was verified the ultimate strength of her structural's members (Fig 5). Detail to highlight is the use almost entirely of section 25 x 150 mm. In this regard, as a whole, "Roof truss" is important from this phase of the project onwards.

Table 4 Truss beams verifications

No	Type	Denom	Section		※ I	Length l	Allowable stress			Span L	Weight	L/400 δmax	V Def δ	Verif M Mmax	Allowable momento	Shear Stress
							c	b	s							
			width	height	cm4	cm	N/mm2	N/mm2	N/mm2	mm	N	mm	mm	N.m	N.m	N/mm2
1	beam	eucalyptus	5	15	1406	2992	13	24,35	3,11	1012	750	2,53	1,00	49	281	1,5
2	beam	eucalyptus	5	15	1406	988,2	13	24,35	3,11	988,2	620	2,47	0,90	62	281	1,24
3	beam	eucalyptus	10	30	22500	2765	13	24,35	3,11	1515	1370	3,78	1,29	62	281	1,37
4	beam	eucalyptus	10	30	22500	3216	13	24,35	3,11	3216	2610	8,04	6,85	637	1452	2,61

※ I :Moment of inertia

It also verified the resistance of members to pull the wind. Here apply the Japanese Standard for Structural Design. For the elements of the "Ceiling," it was considered an admissible stress deformation, in the order of $\delta = l/400$. In addition, the fixed values for verification must confirm that the force of the wind will not cause any damage to the building or on the joints (Table 4).

4.3.2 Bearing wall

In design of bearing wall, the first point to consider is "The amount of wall," to resist earthquake forces. In Japanese building codes, necessary amount of wall for earthquake resistance is shown in Fig 8. The procedure to determinate the earthquake length was considering the product of each floor area by the coefficient from Fig. 8.

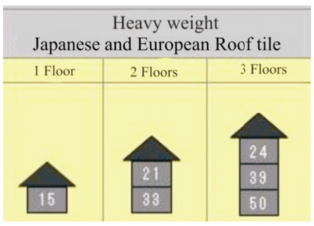


Figure 8 Coefficient of wall by earthquake forces

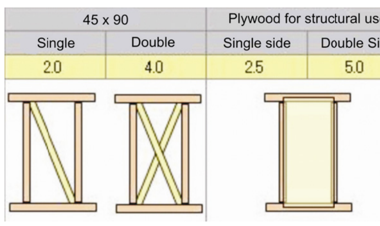


Figure 9 Bearing Wall coefficient

Table 5 Lengths of wall to earthquake conditions and Wind pressure

Level	Total area m^2	Elevation area m^2	Necessary amount of wall: Earthquake (length) m	Necessary amount of wall: Wind (Length) m	Amount of wall: Project (Length) m
1st Floor X	49.91	38.63	16.47	19.31	48.24
1st Floor Y		43.61	16.47	21.80	30.70
2nd Floor X	44.00	10.63	9.24	5.31	40.16
2nd Floor Y		15.61	9.24	7.28	30.11

There are two types of ratios, for a windy region and for a general region. The wall coefficient to wind pressure, it is estimated between 50 and 70 cm/m^2 for the most attacked region (windy region) and 50 for regions in general. Calculations results come from the result between the elevation areas by the wind coefficient, the amount of wall are shown in table 5. To estimate the amount of wall of the project use the wall coefficient from Fig. 9 by the quantity of bearing wall panels used in the project.

4.3.3 Wall Balance

In a building when the center of gravity and the distance to the geometric center are great, it is said to be of great eccentricity. The same may be due to the concentration of forces by an earthquake or effect of the wind. The eccentricity grows with the distance to the geometric center. Verifications of Eccentricity pattern and values are shown in Table 6. The results shown that the admission requirements verify (R_{ex} and $R_{ey} < 0.3$), but it's not equal in same direction. Its hope that condition can be affected the final behavior of the structural behavior.

Table 6 Eccentricity pattern and values verifications

	Wall Direction X	Value	Wall Direction Y	Value
Distance from axis to G	$Gx = \frac{\sum(A.X)}{\sum A}$	3.065	$Gy = \frac{\sum(A.Y)}{\sum A}$	2.392
Distance from axis to center	$Sy = \frac{\sum(Lx.Y)}{\sum Lx}$	2.985	$Sx = \frac{\sum(Ly.X)}{\sum Ly}$	2.161
Eccentric value	$ex = \lvert Sx - Gx \rvert$	0.080	$ey = \lvert Sy - Gy \rvert$	0.230
Twist Rigidity	$Kr = \sum(Lx(Y - Sy)^2) + \sum(Ly(X - Sx)^2)$			128.1908
Elasticity	$r\,ex = \sqrt{Kr/\sum Lx}$	1.539	$r\,ey = \sqrt{Kr/\sum Ly}$	1.596
Eccentricity of rate	$Rex = {ey}/{r\,ex}$	0.051	$Rey = {ex}/{r\,ey}$	0.144

4.4 Joints

The conduct this research here in Japan, has as its reference point, enrichment and a firsthand approach to the whole culture of wooden projects, where the joints are resolved without metallic accessories, nails or bolts. Conducting an investigation on this issue was a good complement to the understanding the design. Applying the traditional Japanese type of joints is a difficult process in the project. They have no benchmarks established for the verifications, so that each case should be studied for these endpoints to be verified according to the solicitations. Then, bolts and Nails are used in the design of joints. The system of Japanese standard for structural design of timber structures provides resistance according to the diameter and length of the nail or bolts. In this case establishes a partial load, by bolt or nail, and then would be to see how many bolts and / or nails are used in the design of joint, in order to know if checks verified. Other joints of the project, proposed the use of 2x4 system, or what is the same include the use of metal plates in the project. Here was appealed to the HOWTEC studies (Japan Housing and Wood Technology Center) conducted for each type selected and thus obtain the resistance offered each separately.

5 STRUCTURAL ANALYSIS

5.1 Static Analysis

Static analysis was carried out by using structural analysis software "Sap 2000". The joints of the structure are modeled as hinge to take into account the rotation of the joints. The points where loads were applied for the static analysis are shown in Fig. 8 and 9. The loads were applied simultaneously at three points at the top of each floor. The seismic force for each floor obtained with eq. (4.6) is divided by 3 and applied to the mentioned points. From the results of displacement, is possible to observe that the central part of the structure has the larger displacement, (see Fig 10). In Table 7 the drift angle for each point are shown.

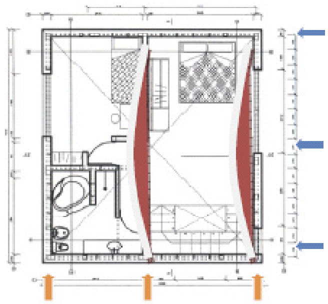


Figure 8 Plan

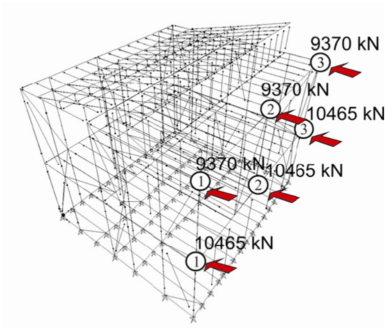


Figure 9 Location loads

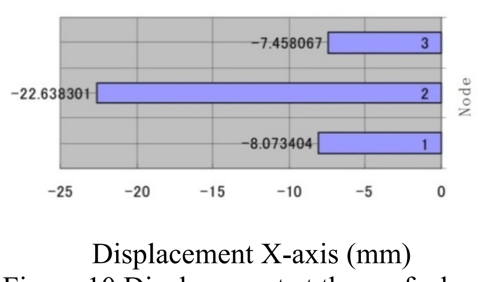


Figure 10 Displacement at the roof edge

Table 7 Displacement (rad)

Node No	1	2	3
Rotation angle (rad)	1/400	1/120	1/350

As a result of this static analysis, central part of the roof has larger deformation, since the rigidity of roof plane is low. In case of adding panels in plane of the roof, it would provide better distribution of the displacements by acting as rigid diaphragm. The inclusion in the whole of the ceiling panels offers a solution such that the second floor is moved in line with the values of the first floor. Maximum drift angle is not over 1/120 rad (table 7), this maximum value come from the Japanese standard and confirm the adequacy with the admitted requirements.

5.2 Modal Analysis

The modal analysis permits to obtain the natural periods and mode shapes of the structure. That is, the more dominant dynamic characteristics of the structure are obtained to study the manner in which vibrates the structure (see table 8). In the earthquake response problem, the 1st mode component dominates in most cases and the effect of higher modes is generally small. Therefore, the limited number of modal response (up to the 3rd mode for overall building response) can be used for the maximum response estimation.

The longest period is obtained for the large direction indicating that the structure has smaller stiffness in that direction. Since analysis is performed considering 3 dimensional behaviors, Torsional mode of vibration is obtained as a 3rd mode, which could be an indicator of a non-uniform distribution of the stiffness in each story, in special in the 1st floor.

Table 8 Modal Periods and Frequencies

Mode Nº	Mode Shape	Period (S)	Frequency (Hz)
1	Horizontal normal mode in large direction (Y)	0,1241	8,058
2	Horizontal normal mode in short direction (X)	0,0869	11,501
3	Torsion in plant	0,062	16,138

In the dynamics analysis, for the calculation of the mass of the structure, 1/3 of the live load was included according with the Japanese Code. With these admitted values, was verify first the period of the structure, verifying values according to Japanese standard T <0.3 x h.

5.3 Time-history response analysis

Verified the previous point; it proceeded to analyze the behavior of the structure. Thus, it was decided to apply the Kobe earthquake-NS (PGA 805Gal) and the Northridge earthquake-Saticoy-NS (PGA 477Gal) and was obtained for the same the following information regarded as the most important points of the structure (see Figure 11, Table 9 and 10).

The correspondent response spectra for each earthquake are shown in Fig. 12. It was observed the greatest acceleration of response given in Northridge-Saticoy due to the period of the structure. In contrast with the previous results, the larger displacements are shown in the spectra of displacement of Kobe-NS and her representation is shown in Fig. 13. Observing this information, we find that the points 12, 14 and 16 have a greater displacement in the Y axis that the whole structure. Similarly, the points 2, 8 and 12 have a greater displacement in the X axis.

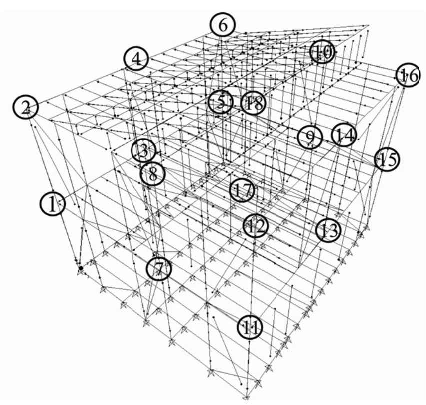


Figure 11 Selection points

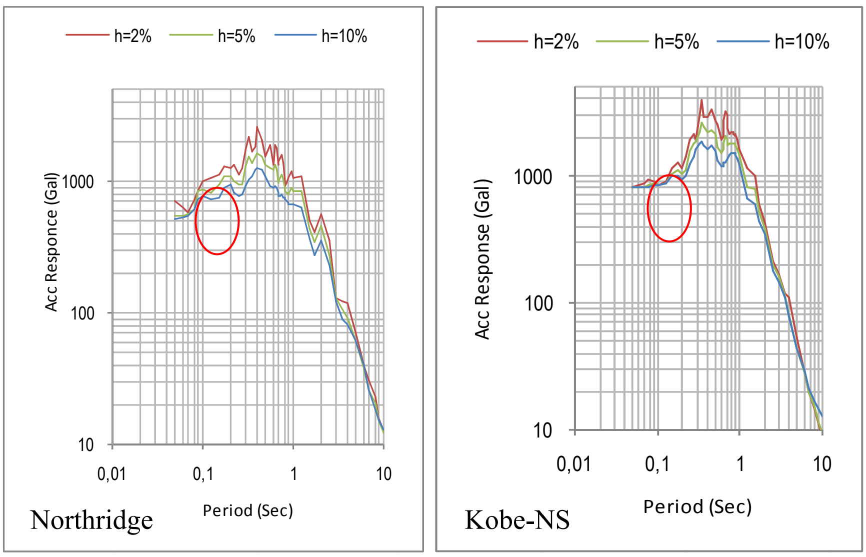


Figure 12 Earthquake response Spectra N.Saticoy and Kobe

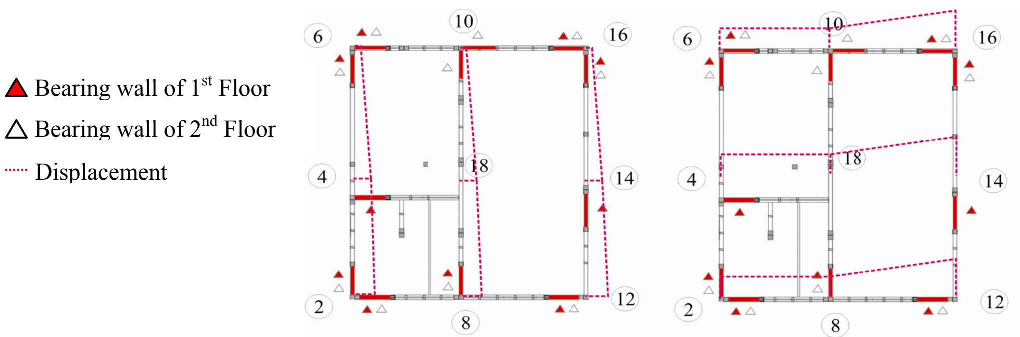
It would be interesting to determine a spectrum of design and determine on this basis, what response would be more damaging to the structure, this will be an issue to develop in follows steps.

Table 9 Data Northridge-Saticoy-NS

Axis X N-Sati-NS				Axis Y N-Sati-NS			
	Disp X	Acc X	Vel - X		Disp Y	Acc Y	Vel - Y
1	0,473	4687,33	21,42	1	0,884	5028,6	35,29
2	1,707	6775,95	77,15	2	3,203	8410,9	128,04
3	0,423	4707,53	18,63	3	0,883	5027,8	35,13
4	1,631	6428,89	71,95	4	3,176	8357,8	126,94
5	0,382	4739,86	16,22	5	0,868	5022,1	34,64
6	1,414	5796,55	60,33	6	3,205	8405,9	128
7	0,496	4690,18	22,49	7	1,041	5081,9	42,59
8	1,663	6693,86	75,22	8	3,169	8358,4	129,46
9	0,395	4743,35	16,67	9	1,035	5082	42,24
10	1,380	5735,99	58,82	10	3,172	8332,6	129,42
11	0,507	4693,28	22,95	11	1,307	5280,5	54,24
12	1,661	6685,95	75,08	12	3,829	10044	158,97
13	0,428	4707,52	18,84	13	1,288	5259,7	53,44
14	1,624	6418,68	71,69	14	3,847	10095	159,82
15	0,394	4743,33	16,6	15	1,171	5123,6	48,57
16	1,388	5752,56	59,2	16	3,844	10099	159,79
17	0,417	4706	18,38	17	1,078	5102	44,03
18	1,622	6415	71,63	18	3,153	8302	128,77

Table 10 Data Kobe-NS

Axis X Kobe-NS				Axis Y Kobe-NS			
	Disp X	Acc X	Vel - X		Disp Y	Acc Y	Vel - Y
1	0,559	5746,7	14,82	1	0,975	6035,1	25,94
2	2,017	6600,6	53,5	2	3,496	7314,6	94,05
3	0,505	5750	12,96	3	0,977	6032,8	25,88
4	1,944	6558,9	50,15	4	3,465	7275,3	93,24
5	0,462	5752,2	11,39	5	0,956	6027,3	25,47
6	1,707	6420,2	42,36	6	3,501	7318,5	94,07
7	0,584	5759,1	15,6	7	1,118	6125	30,72
8	1,964	6574,2	52,19	8	3,426	7219	93,5
9	0,478	5751,4	11,68	9	1,113	6120	30,52
10	1,667	6394,4	41,26	10	3,438	7218	92,55
11	0,598	5767	15,93	11	1,371	6267	38,61
12	1,963	6568,9	52,07	12	4,026	8240	113,11
13	0,510	5749,6	13,11	13	1,349	6257	38,04
14	1,936	6555	49,98	14	4,042	8268	113,67
15	0,479	5752,1	11,57	15	1,229	6197	34,59
16	1,676	6400,7	41,54	16	4,035	8263	113,6
17	0,497	5751	12,79	17	1,159	6142	31,8
18	1,934	6554	49,93	18	3,415	7191	93,03



X Axis Y Axis

Figure 13 Representation of displacement

The non-uniform distribution of the stiffness in each story generates a non-uniform displacement of the entire structure producing a particular behavior of the structure.

6 CONCLUSIONS

This investigation caused much interest in the structural use of Uruguayan timber, and the one conclusion it was to be capable in the structural use. Has been applied the Uruguayan wood in housing design and hope will be extend its use.

The project proposes an optimal structure design with suitable sections for the region. Also, the non-uniform distribution of the stiffness in each story generates a non-uniform displacement of the entire structure. Relationship between dynamic behavior and the eccentricity behavior, found that even through the final values are different but the results confirm the values admitted by Japanese code.

Moreover, for comprehend the real structural behavior it is possible to determine the spectrum design and on this basis, what is its response and how much damage made on the structure, this will be an issue to develop in follows steps.

With this result, this research hopes to support the promotion of wooden frame use and motivate the internal evaluation of respective law to permit its applicability.

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