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SEISMIC DESIGN SPECTRA FOR OFFSHORE PLATFORMS AT THE BAY OF CAMPECHE USING ISO GUIDELINES

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SUMMARY

In this paper are presented values of Extreme Level Earthquake spectral acceleration (Sa_{ELE}) taking into account the standard deviation of uncertainties not captured in the seismic hazard curve (σ_{LR}) and seismic reserve capacity factor (Cr). It was used the seismic action procedure proposed by ISO documents **19901-2** & **19902** for the design of fixed steel offshore structures. Besides employing the target annual probability of failure (P_f) as a function of the exposure level recommended by the Mexican code, following a detailed seismic action procedure. The Sa_{ELE} is modified for local soil conditions at the Bay of Campeche.

INTRODUCTION

The Mexican offshore sector provides fairly 80 % of the oil production in the country, and in October 1995 the hurricane Roxanne meandered in this zone (Bay of Campeche) for several days causing death and destruction along the coast of Mexico and some damage to the PEMEX's offshore facilities. This hurricane has been the most severe that has affected the area during this century **[1]**. This event started a series of meeting IMP-PEMEX personnel in order to develop the Mexican code for requalification and design of the offshore facilities to be placed at the Bay of Campeche.

In the late 1970's started the first efforts to gather the information about the seismic environment around the Bay of Campeche and its vicinity. These studies increased in 1995 and continue nowadays: Guerra & Esteva **[2]**; Guzmán **[3]**; Chávez **[4, 5]**; Bea **[6]**; García *et* al **[7-9]** and Pérez **[10]**.

EARTHQUAKE SOURCE CHARACTERIZATION

Risk Assessment and Management (RAM) approach was used in order to determine the seismic design spectra. In which, seismic conditions and their uncertainties are integrated with the performance characteristics of alternative platform configurations, including the biases and uncertainties usually found on the platform seismic response and the reliability level associated with these configurations.

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Three primary types of earthquake sources that have been identified in previous studies, Chávez **[4, 5]**, influence the seismic environment. These events have the following characteristics:

Type I Associated with the subduction zone on the western pacific coast of Mexico, epicenters at depths of 15 to 20 km and magnitudes up to Ms = 8.2.

Type II Associated with the lithospheric slab within the central portion of Mexico, epicenters at depths of 60 to 250 km and magnitudes up to Ms = 7.5.

Type III Associated with the Trans-Mexican volcanic belt located along the east cost of Mexico, epicenters at depth up to 20 km and magnitudes up to Ms = 6.7.

The previous information is summarized in Table 1.

Table 1. Characteristics associated to each Type of event

Type	***Ms***	**H (km)**
I	< 8.2	15 – 20
II	< 7.5	60 – 250
III	≤ 6.7	< 20

On the other hand, were developed for Mexico and its seismotectonic conditions attenuation relationship by Chávez & Castro **[11]** to characterize the propagation features of the three types of seismic events affecting the Bay of Campeche. For this reason, it can be concluded that seismic risk will be dominated by the Type II earthquake source.

In Figures 1 and 2 are presented the epicenters of seismic events affecting the Bay of Campeche and its vicinity from all seismic sources during the period 1900 to 2001. The former with $Ms \geq 1.0$ and the latter with $Ms \geq 5.0$ **[10].**

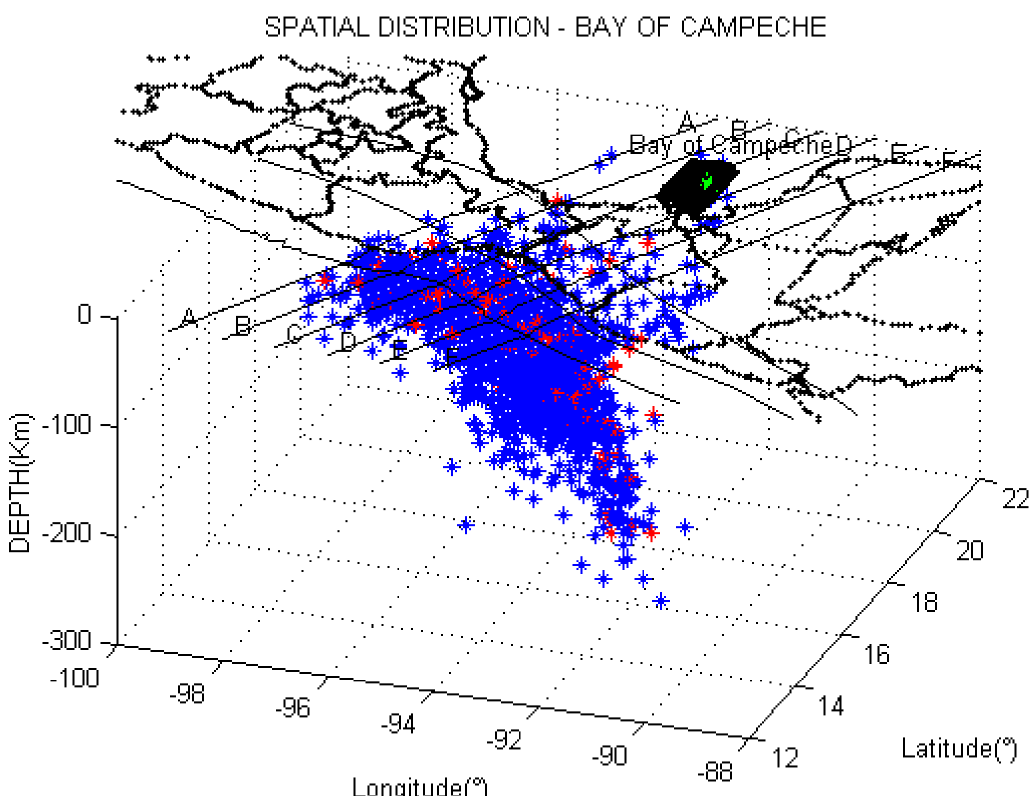

Figure 1. Seismic events ($Ms \geq 1.0$) affecting the Bay of Campeche region, 1900-2001 [10]

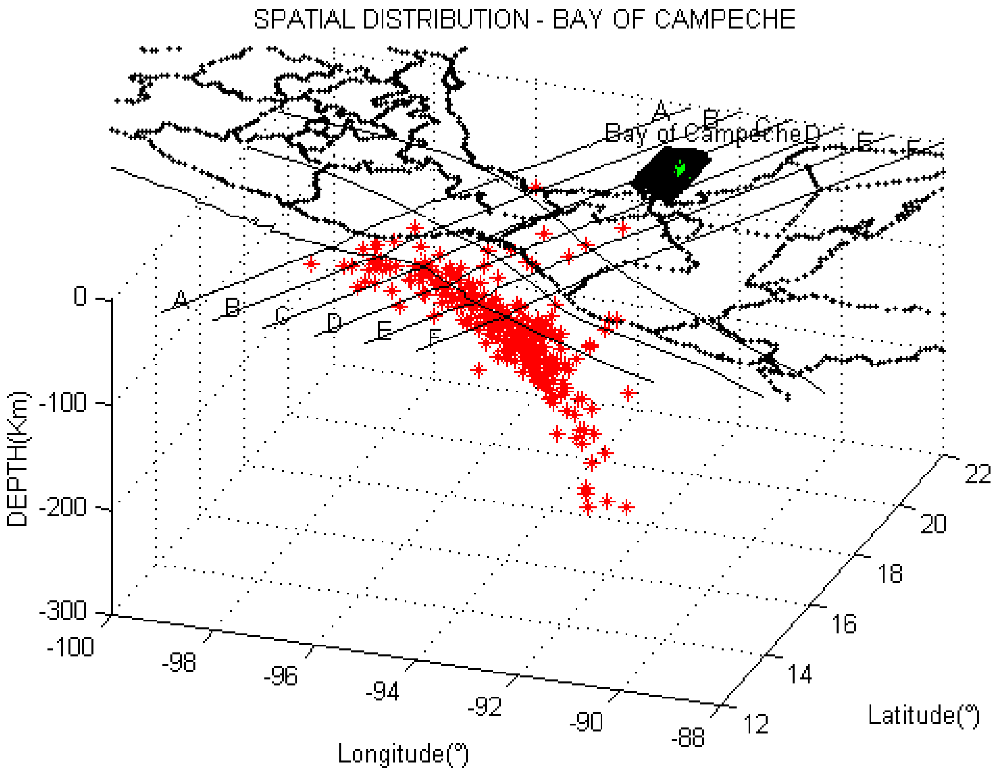

Figure 2. Seismic events ($Ms \geq 5.0$) affecting the Bay of Campeche region, 1900-2001 [10]

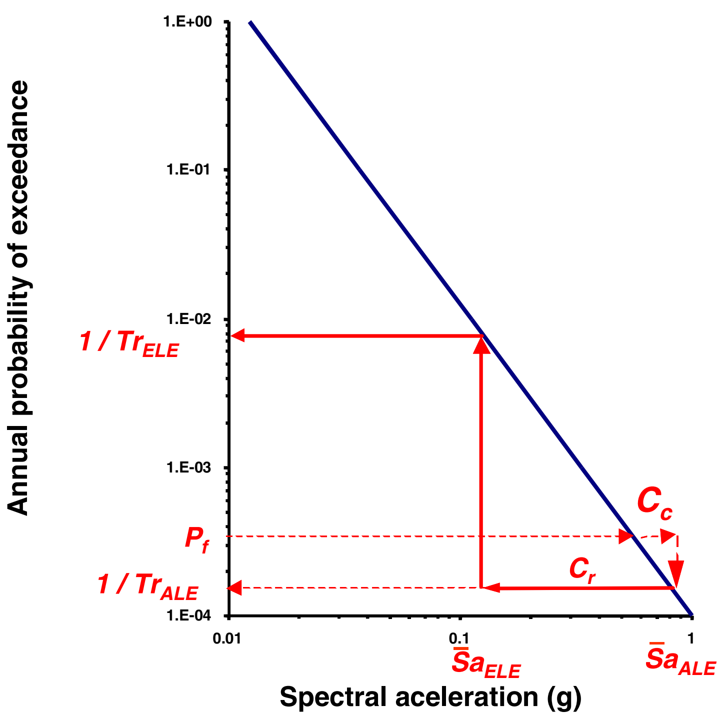

Figure 3. Seismic hazard curve and general procedure to obtain probabilities and accelerations values at ALE & ELE [13]

LEVELS OF TARGET P_f

PEMEX is the Oil State Company in charge of extraction, production and distribution of hydrocarbons in Mexico, and needs to ensure level of target probability of failure, P_f, of its offshore platforms. The recommended P_f by the Mexican code **[12]** are smaller that those recommended by ISO documents **19901-2** and **19902 [13, 14],** as is shown in table 2.

In this work, the general procedure from ISO **19901-2** (Figure 3) is taken to determine seismic design spectra for offshore platforms in the Bay of Campeche using the target *Pf* of PEMEX code **[12]**.

For design of new offshore facilities, the Mexican code considers only a unique category of exposition as a "Very High" consequence of failure without notice the service and the handle oil production volume managed (Table 2).

Table 2. Target annual probability of failure, *Pf*, according to the Exposure Category of the platforms from ISO 19901-2 [13] and PEMEX [12]

Exposure Category	Consequences of failure	p_f		β design PEMEX
		ISO 19901-2	PEMEX (Design)	
L1	High	1/2500 = 0.0004	1/5000 = 0.0002	3.60
L2	Medium	1/1000 = 0.0010	1/5000 = 0.0002	3.44
L3	Low	1 / 400 = 0.0025	1/5000 = 0.0002	3.33

CORRECTION FACTOR, C_C

The correction factor (Cc) depends of two factors: 1) the relative importance of additional uncertainties which are not captured in the seismic hazard curve (σ_{LR}), and 2) the slope of the seismic hazard curve (a_R). According to **ISO 19901-2 [13],** a value of σ_{LR} = 0.3 is judged to be representative of these uncertainties. In certain cases where the calculation of seismic loads or structure resistance are more uncertain, higher values of correction factor (Cc) may have to be used.

In some previous works, Chávez **[4, 5]**, has been considered that the earthquake source Type II induces the maximum hazard to the Bay of Campeche. For this reason, in the next figures will be referred only to Type II earthquake source, horizontal component.

In Figure 4 is shown the variation of Cc for different values of σ_{LR} due to target annual probability of failure (Pf). Factor Cc is fairly uniform without notice of Pf. On the contrary, the influence of σ_{LR} on Cc is very important.

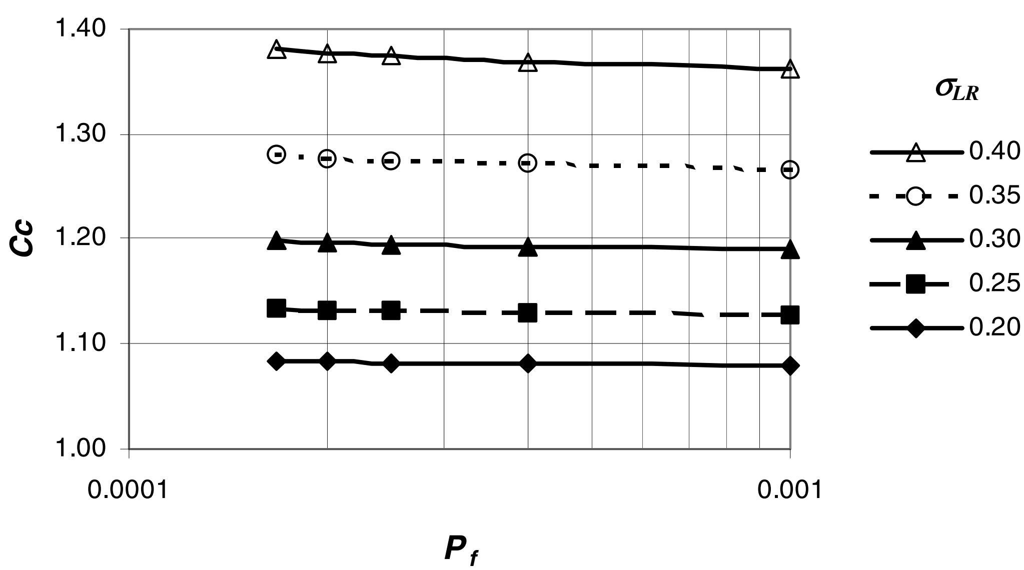

Figure 4. Variation of *Cc* for different values of σ_{LR} due to target annual probability of failure (*Pf*)

FROM Sa_{ALE} TO Sa_{ELE} FOR DIFFERENT σ_{LR} VALUES

When exposed to an Extreme Level Earthquake (ELE) a structure should retain its full capacity for all subsequent conditions **[13]**. In Figures 5, 6 & 7 are shown the ELE spectral acceleration (Sa_{ELE}), the ELE return period (Tr_{ELE}) and the ELE probability of failure (Pf_{ELE}), as a function of σ_{LR} for different values of seismic reserve capacity factor (*Cr*), respectively. It can be appreciated how *Cr* is able to take different values instead of be equal to 2 **[15]**.

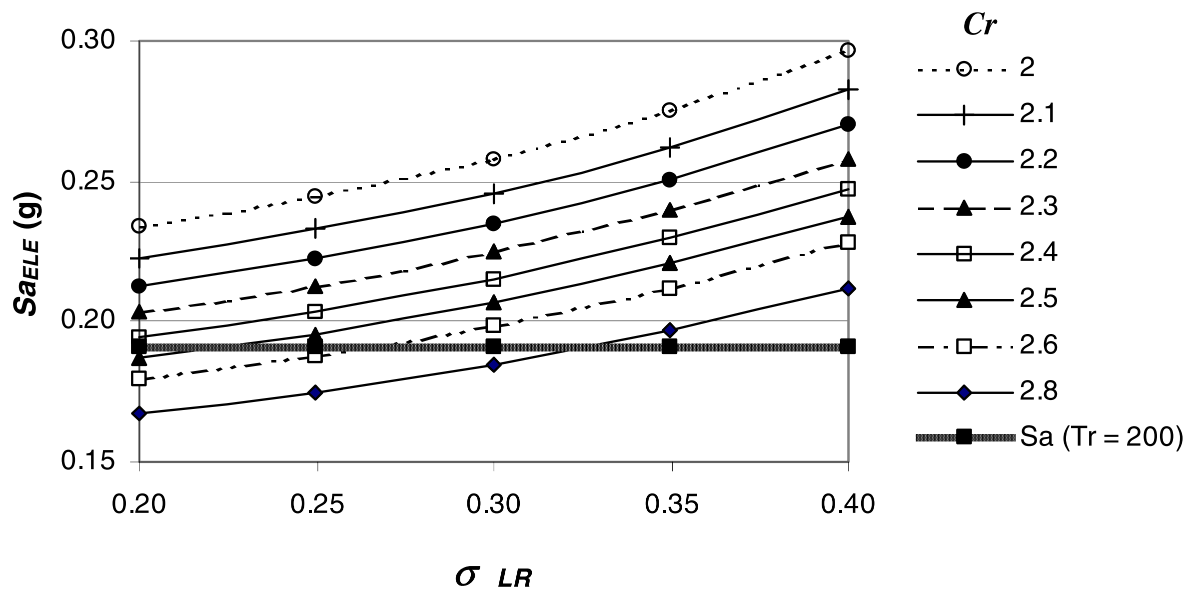

Figure 5. ELE spectral acceleration (Sa_{ELE}) *vs* uncertainties which are not captured in the seismic hazard curve (σ_{LR}) for different values of seismic reserve capacity factor (*Cr*)

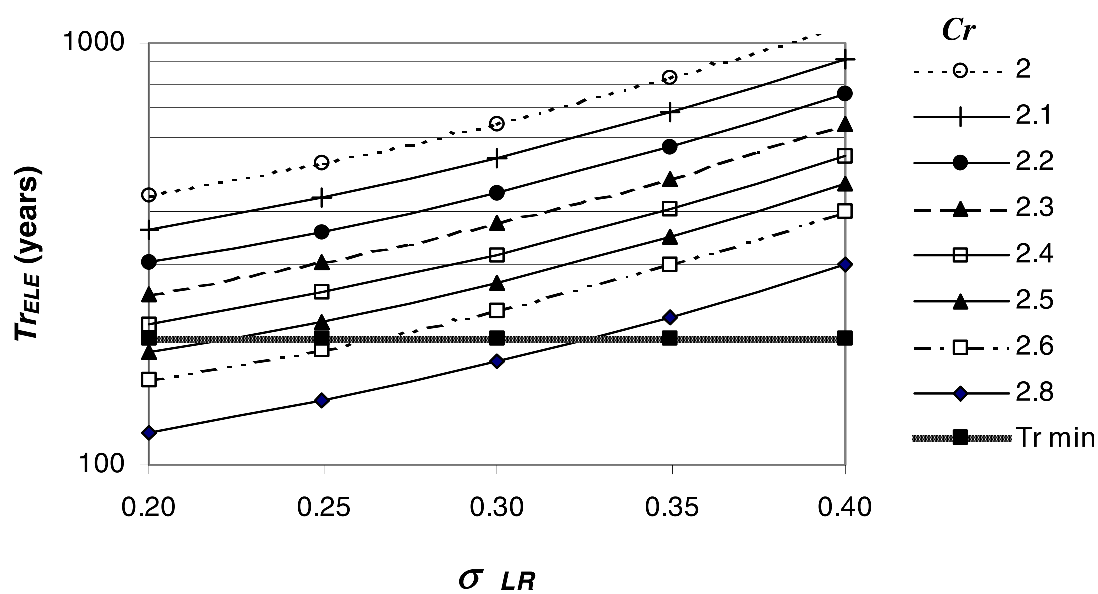

Figure 6. ELE return period (Tr_{ELE}) *vs* uncertainties which are not captured in the seismic hazard curve (σ_{LR}) for different values of seismic reserve capacity factor (*Cr*)

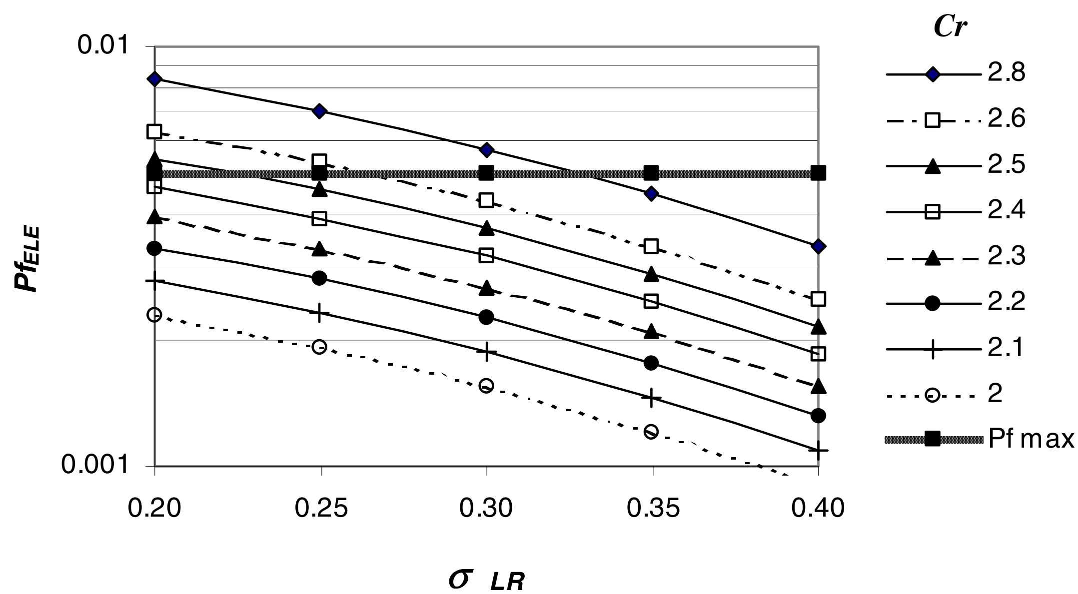

Figure 7. ELE probability of failure (Pf_{ELE}) *vs* uncertainties which are not captured in the seismic hazard curve (σ_{LR}) for different values of seismic reserve capacity factor (*Cr*)

In Figure 8, it can be observed a comparison of the variation between Sa_{ELE}/Sa_{ALE} & Pf_{ELE}/Pf_{ALE} for different *Cr* factors, considering $\sigma_{LR} = 0.30$.

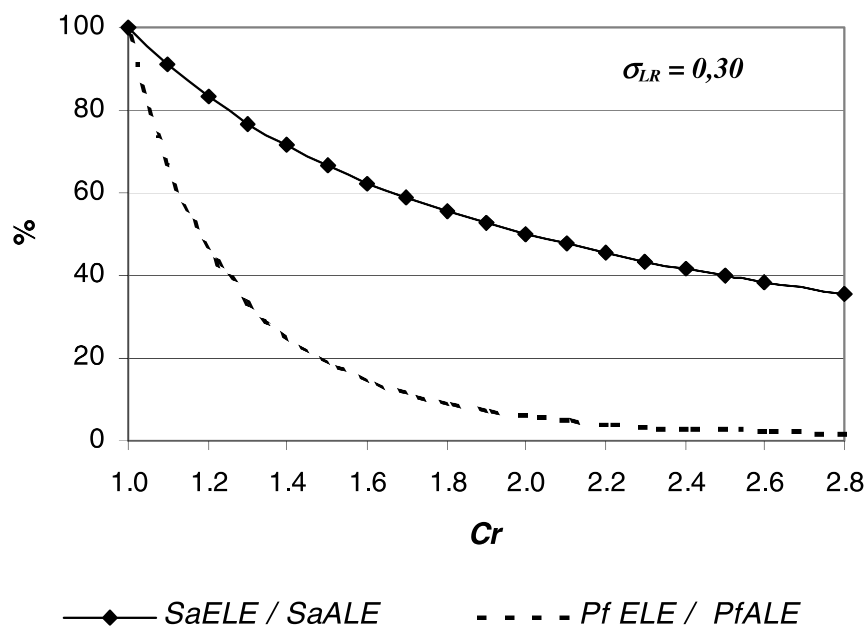

Figure 8. Comparison of the variation between Sa_{ELE}/Sa_{ALE} & Pf_{ELE}/Pf_{ALE} for different *Cr* factors, considering $\sigma_{LR} = 0.30$

RELATIONSHIP AMONG Sa_{ALE}, Sa_{ELE}, C_r, T_r & Pf

With information presented above were obtained some equations which let us to know the relationship among the factors involve to get Sa_{ELE}. Using equation (1) is possible to obtain Sa_{ALE} if it's known σ_{LR}. Additionally, with equation (3) if it's know Sa_{ALE} for a σ_{LR} can be calculated Tr. Finally, equation (4) let us know the target Pf for the Sa_{ELE}, Cr & σ_{LR} chosen. With equations (1) to (2) can be done plot like Figure 9. This is an easy way of observing the relationship among Sa_{ELE}, Cr & σ_{LR}.

$$Sa_{ALE} = 0.364 \cdot \exp(1.1983 \cdot \sigma_{LR}) \qquad \sigma_{LR} \leq 0.5 \tag{1}$$

$$Sa_{ELE} = \frac{Sa_{ALE}}{Cr} \qquad 2.0 \leq Cr \leq 2.8 \tag{2}$$

$$Tr = 69675 \cdot (Sa_{ALE})^{3.9825} \qquad 7500 \leq Tr \leq 1000 \text{ years} \tag{3}$$

$$Pf = \frac{1}{Tr} \tag{4}$$

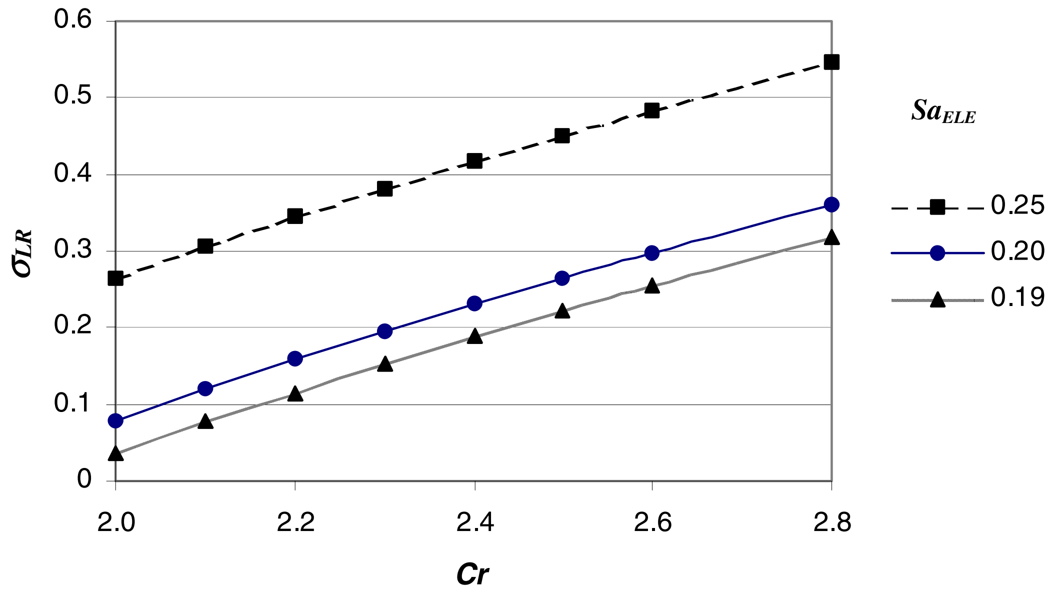

Figure 9. Plot using equations (1) & (2) for three Sa_{ELE}, for different Cr & σ_{LR} values.

Additionally, for a particular case when $\sigma_{LR} = 0.30$; we will have:

$$Tr_{ELE} = a \cdot Cr^{b} \tag{5}$$

$$a = 1.5429 \cdot Tr^{1.034} \tag{6}$$

$$b = -0.0887 \cdot \ln(Tr) - 3.2294 \tag{7}$$

Equations (1) to (7) let us to know a little bit more about the minimum ELE return period Tr_{ELE} **[13]** and the spectra proposed by Pérez **[10]** $Sa_{ELE} = 0.20$ g (Tables 3 & 4). The three Sa_{ELE} (Tr_{ELE}) shown on Table 4 are plotted in Figure 10.

Table 3. Minimum ELE return period, ISO 19901-2 [13]

Exposure Category	Tr_{ELE} minimum (years)
L1	200
L2	100
L3	50

Table 4. Relationship among different Tr_{ELE}, Pf_{ELE}, Sa_{ELE}, σ_{LR} & Cr values using equations (1) to (7). Type II earthquake source, horizontal acceleration

Tr_{ELE} (years)	Pf_{ELE}	Sa_{ELE} (g)	σ_{LR}	Cr
200	0.00500	0.19	0.33	2.8
			0.30	*2.7*
			0.20	2.3
240	0.00417	***0.20***	0.36	2.8
			0.30	*2.6*
			0.20	2.3
560	0.00179	***0.25***	0.40	2.4
			0.30	*2.2*
			0.20	1.9

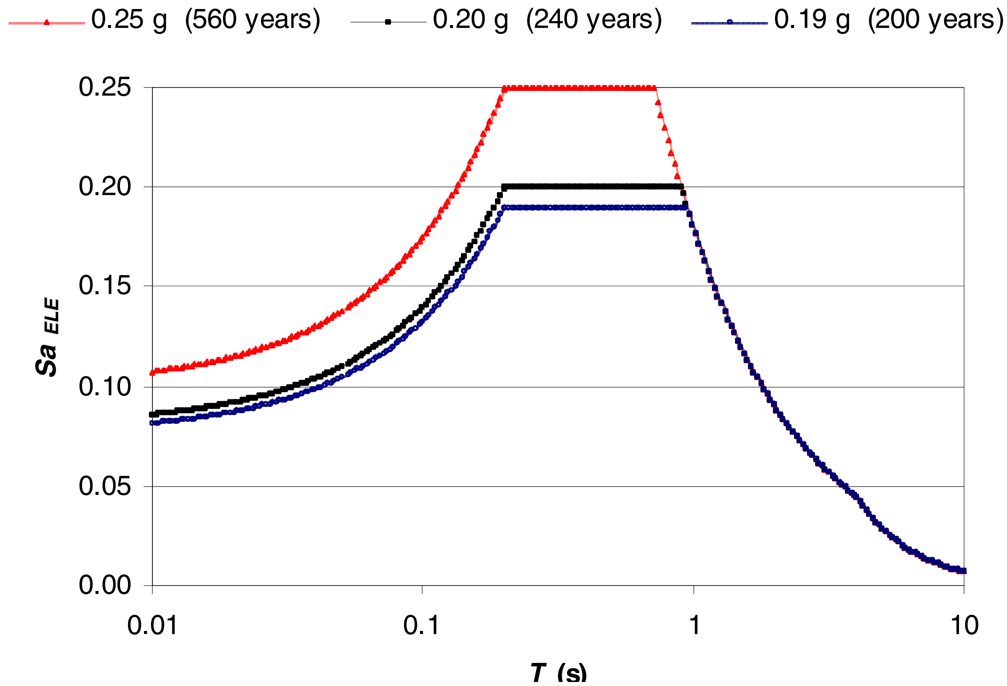

Figure 10. Plot of the Sa_{ELE} of Table 4, here it cannot be seen the σ_{LR} and the Cr used

Sa_{ELE} is already modified for local soil conditions. The site coefficients Ca and Cv for deep pile foundations are taken from **ISO 19901-2 [13]** and a study done by Ruvalcaba **[16].**

CONCLUSIONS

According with previous information about the seismic environment in the Bay of Campeche and its vicinity, and following a detailed seismic action procedure are obtained some relationship among the principal factors involved for designing of offshore platforms.

Equations (1) to (4) presented an the end of this study can be employed in order to calculated ELE spectral acceleration (Sa_{ELE}), for different values of Cr, Pf, σ_{LR} and its consequences on the seismic design spectra presented. Additionally, for a particular case when σ_{LR} = 0.30 it can be used equations (5) to (7) to calculated ELE return period (Tr_{ELE}) given Cr, Tr & Sa_{ELE}. On the other hand, Sa_{ELE} is already modified to take into account local soil conditions.

The shape of the seismic design spectra and the factor used in this study are according with that proposed by ISO documents 19901-2 & 19902, employing the target probability of failure recommended by the Mexican code for seismic design of offshore platforms at the Bay of Campeche.

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