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# DETERMINATION OF THE IMPACT OF THE LOAD ON BUILDINGS FOR THE SUBSEQUENT OPTIMAL CHOICE OF THE ORGANIZATIONAL AND TECHNOLOGICAL SOLUTION OF THE CONSTRUCTION PROJECT

*The present document helps to determine the impact of loads on buildings for the subsequent optimal choice of the organizational and technological solution of the construction project.*

*In further studies it is shown that the effect of loads has a major influence on the process of construction and the optimization of the time cost efficiency. The known literatures describe the loads as a statistical variable which is related to the local, environmental and useable conditions of the project.*

*All types of loads, static and dynamic, directly reduce or increase the cost of the project, it depends of the consideration taken during the design. For example, the main variable that will be considered in this document is the soil effect on the cost of the structure under static and dynamic loads, if it is taken or not into account during the design of the superstructure, and how it changes the whole behavior of any structure making it more rigid or more flexible.*

*A particular study is done here down in this document showing the effects of soil on two different buildings during a dynamic impact (seismic event in our case). Moreover, this document provides with the needed formulas and tools to describe the soil material in 3D design softwares. The use of these tools will let the structural designer to change the response spectra curve and reduce the influence of the dynamic impact on the building. Thus, a comparative table will show the difference between the use of rigid base models and flexible ones to spotlight the effects of the soil. Furthermore, a sensitivity study is done showing the contribution part of some formulas in the soil consideration.*

*The reduction in the base shear will allow the client and contract to reduce the budget of the project and by this an optimization of the constructional time can be done.*

***Keywords: Load impact, organizational and technological solution, optimization, cost efficiency, Soil Structure Interaction, Static Load, Dynamic Load***.

**Problematic:** Civil engineers usually use 3D softwares during the design of the structures and the simplest way to model their bases is the use of fixed supports. This assumption does not describe the reality of the soil-structure's effects. The use of a more flexible base will be more realistic in some cases where in other no, and will have a major impact on the load distribution in the structural elements.

Soil Structure Interaction effects are considered through 2 ways: Modeling of the soil and structure using finite elements, which is not an optimal solution for commercial projects, or the use of springs and dashpots to model the soil flexibility which will be considered here.

1. The behavior of the structure under static loads is described by vertical springs that offers the real flexibility of the soil under the foundation. Three methods are used to describe this flexibility:

a) The modeling of spread footings using one spring under the supporting elements with the following formulas:

$$K_{SV}(KN/m) = \frac{GB}{1-\nu}\left[3.1\left(\frac{L}{B}\right)^{0.75} + 1.6\right],$$

$$K_{sr}(KN.m) = \frac{GB^3}{1-\nu}\left[3.73\left(\frac{L}{B}\right)^{2.4} + 0.27\right],$$

where L and B are the long and short sides of the foundation respectively, G and $\nu$ the shear modulus and Poisson ratio.

Note: $K_{SV}$ is the vertical spring stiffness and $K_{sr}$ is the rotational spring stiffness.

b) The use of the Winkler model for spread footings or mat foundations using one of these two formulas:

$$K_{SV}(KN/m^3) = \frac{1.3G}{B_f(1-\nu)}$$

$$K_{SV}(KN/m^3) = \frac{G}{4 \times L(1-\nu)}\left[3.1\left(\frac{L}{B}\right)^{0.75} + 1.6\right]$$

c) The use of the Winkler method (same formulas) but with stiffer springs at the edge:

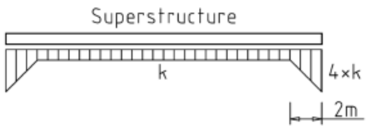


*Fig.1: Winkler method with stiffer springs at the edges*

The three methods above simplify the soil to structure behavior for projects by using the minimum needed parameters and giving the more accurate results.

2. During a dynamic impact, a structure interacts with the soil beneath through two ways:

➢ **Kinematic interaction** that is governed by two main participants (A) Base slab averaging and (B) embedment effects.

**Formulas to consider (A):**

$$b_e(m) = \sqrt{A_{base}} \leq 79.3m$$

$$b_0(m) = 0.0023\left(\frac{b_e}{T}\right),$$

where $T(s) \geq 0.2s$ is the period of the structure for the first fundamental mode.

$$B_{bsa} = \begin{cases} 1 + {b_0}^2 + {b_0}^4 + \dfrac{{b_0}^6}{2} + \dfrac{{b_0}^8}{4} + \dfrac{{b_0}^{10}}{12} & b_0 \leq 1 \\ \exp(2{b_0}^2)\left[\dfrac{1}{\sqrt{\pi b_0}}\left(1 - \dfrac{1}{16{b_0}^2}\right)\right] & b_0 > 1 \end{cases}$$

$$RRS_{bsa} = 0.25 + 0.75\{\frac{1}{{b_0}^2}[1 - (\exp(-2{b_0}^2)) \times B_{bsa}]\}^{1/2} \geq 0.7$$

**Formula to calculate (B):**

$$RRS_e = 0.25 + 0.75 \times \cos\left(\frac{2\pi e}{TV_s}\right)$$

where “e” is the embedment height and $e \leq 6m$ (for greater values of “e” use 6m), T and Vs are respectively the modal period of the first fundamental mode defined on the response spectra (limitation $T \geq 0.2s$) for the fixed base model and the effective shear wave velocity at embedment “e”.

Finally, $RRS_{bsa}$ and $RRS_e$are the reduction coefficients that should change each value of the response spectra, and by this changing its value, by decreasing the acceleration of the vibration.

➢ **Inertial interaction** that is governed by three main participants (A) period lengthening which is the increasing of the fundamental period where it is directly related to the structure’s shape and foundation type, (B) radiation damping which is the generation and propagation of waves away from the foundation, (C) soil damping which is the hysteretic (material) damping of the soil.

Furthermore, in the following are described the required steps to consider this Inertial interaction and compute the reduction or increasing in the base shear:

1) Calculate the horizontal translation foundation stiffness

$$K_y(KN/m) = \frac{GB}{2-\nu}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 0.8\left(\frac{L}{B}\right) + 1.6\right]$$

or

$$K_y(KN/m) = \frac{GB}{2-\nu}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 2.4\right].$$

2) Calculate the rotational foundation stiffness

$$K_{xx}(KN.m) = \frac{GB^3}{1-\nu}\left[3.2\left(\frac{L}{B}\right) + 0.8\right]$$

or

$$K_{xx}(KN.m) = \frac{GB^3}{1-\nu}\left[3.73\left(\frac{L}{B}\right)^{2.4} + 0.27\right].$$

3) Calculate $\frac{\tilde{T}}{T}$ where $\tilde{T}$is the period of the first fundamental mode of vibration for the flexible base model and $T$ the one for the fixed base model (both are taken from the 3D model). Calculate the expected ductility demand:

$$\mu = \frac{R}{\Omega} = \frac{Max\ Base\ Shear}{Elastic\ Base\ Shear\ Capacity}.$$

4) Calculate the effective period lengthening ratio

$$\left(\frac{\tilde{T}}{T}\right)_{eff} = \left[1 + \frac{1}{\mu}\left[\left(\frac{\tilde{T}}{T}\right)^2 - 1\right]\right]^{0.5}$$

5) Calculate the dimensionless frequency

$$a_0 = \frac{2\pi B}{\tilde{T}V_S}.$$

6) Calculate the dimensionless

$$\Psi = \sqrt{\frac{2(1-\nu)}{1-2\nu}} \leq 2.5$$

7) Calculate the dimensionless

$$\alpha_{xx} = 1 - \left[\frac{\left(0.55 + 0.01\sqrt{\left(\frac{L}{B}\right) - 1}\right) a_0{}^2}{\left(2.4 - \frac{0.4}{\left(\frac{L}{B}\right)^3}\right) + a_0{}^2}\right]$$

8) Calculate the effective structure height

$h^* = 70\% \times$ The real structural height or Height of the first fundamental mode.

9) Calculate the fundamental translational period

$$T_y(s) = 2\pi\sqrt{\frac{M^*}{K_y}}$$

where $M^* = M_{dynamic\ mass\ of\ the\ structure} \times modal\ participation\ factor.$

10) Calculate the fundamental rotational period

$$T_{xx}(\mathrm{s}) = 2\pi\sqrt{\frac{M^* {h^*}^2}{\alpha_{xx} K_{xx}}}$$

11) Calculate the translational foundation damping coefficient

$$\beta_y = \left[\frac{4\frac{L}{B}}{\frac{K_y}{GB}}\right]\left[\frac{a_0}{2}\right]$$

12) Calculate the rotational foundation damping

$$\beta_{xx} = \left[\frac{4\Psi\left(\frac{L}{B}\right) a_0{}^2}{\left(\frac{K_{xx}}{GB^3}\right)\left[2.2 - \frac{0.4}{\left(\frac{L}{B}\right)^3} + a_0{}^2\right]}\right]\left[\frac{a_0}{2\alpha_{xx}}\right]$$

13) Calculate the effective radiation damping

$$\beta_{rd} = \frac{1}{\left(\frac{\tilde{T}}{T_y}\right)^2}\beta_y + \frac{1}{\left(\frac{\tilde{T}}{T_{xx}}\right)^2}\beta_{xx}$$

14) The foundation damping ratio is as follow:

$$\beta_f = \left[\frac{\left(\frac{\tilde{T}}{T}\right)^2 - 1}{\left(\frac{\tilde{T}}{T}\right)^2}\right]\beta_s + \beta_{rd}$$

where $\beta_s$ is the soil hysteretic damping ratio given by the geotechnical specialist.

15) Calculate the effective viscous damping ratio

$$\beta_0 = \beta_f + \frac{\beta}{\left(\frac{\tilde{T}}{T}\right)_{eff}^2} \leq 0.2.$$

16) Compute the factor to adjust the design response spectrum

$$B_{SSI} = \frac{4}{5.6 - \ln(100\beta_0)}$$

17) Calculate $C_S = \frac{S_{DS}\,(or\ S_a)}{\frac{R}{I_e}}$

where $S_{DS}$ and $S_{D1}$ are determined as per ASCE7-16 sect.11.4 [1].

Limitations can occur on this formula:

For $T \leq T_L$: $C_S = \frac{S_{D1}}{T(\frac{R}{I_e})}$

For $T \geq T_L$: $C_S = \frac{S_{D1} T_L}{T^2(\frac{R}{I_e})}$

$C_S \geq \begin{cases} 0.044\, S_{DS}\, I_e \\ 0.01 \end{cases}$

$I_e$ is the seismic importance factor (refer to ASCE7-16 Table 1.5-2 [1]); $R$ is the response modification coefficient (refer to ASCE7-16 Table 12.2-1 [1]).

18) Calculate the reduction in the base shear coefficient (ASCE7-16 Eq.19.2.2 [1]):

$$\Delta C_S = C_S - \frac{\widetilde{C_S}}{B_{SSI}}$$

19) Calculate the base shear ratio of the flexible to the fixed one:

$$\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}$$

20) Compare $\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}$ with $\alpha = \begin{cases} 0.7 \quad for\ R \leq 3 \\ 0.5 + \frac{R}{15} \quad for\ 3 < R < 6 \\ 0.9 \quad for\ R \geq 6 \end{cases}$ the maximum between the two governs.

21) The reduction in base shear will be as follow:

$$100\% - \left(\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}\ or\ \alpha\right)$$

3. A sensitivity study is done on two of the previously mentioned parameters that affect the response spectra of the structure during a dynamic impact.

The first parameter is the horizontal stiffness where the considered formula is as follow:

$$K_y = \frac{GB}{2-\nu}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 0.8\left(\frac{L}{B}\right) + 1.6\right].$$

The sensitivity of this formula will be plotted considering dimensionless parameters. The variation of L/B and ν will be from 1 to 10 and from 0.2 to 0.5 respectively. The following graph is obtained:

A small variation of the unite less function $\frac{K_y}{GB}$, while varying the Poisson ratio coefficient, is observed in figure 2. An approximate polynomial formula that will be independent of the Poisson ratio ν can be deducted from this surface curve by using a regression. The considered formula is as follow:

$$\frac{K_y}{GB} = -0.0008\left(\frac{L}{B}\right)^4 + 0.0235\left(\frac{L}{B}\right)^3 - 0.2862\left(\frac{L}{B}\right)^2 + 3.4965\left(\frac{L}{B}\right) + 2.3645$$

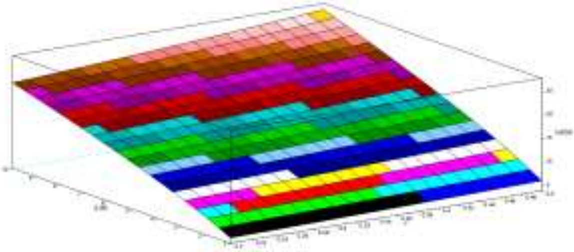

*Fig.2: Curve of* $\frac{K_y}{GB}$ *as a function of ν (the Poisson Ratio) and the dimensions ratio (L/B)*

The maximum observed error for any considered Poisson ratio is 9.12%. Since the code requires a bounding analysis by increasing and decreasing the springs stiffness Ky by 50%, the mentioned error can be neglected.

The second parameter is the effective viscous damping ratio $\beta_0$ that is obtained as a function of the expected ductility demand $\mu = \frac{R}{\Omega}$ and the flexible to the rigid period ratio $\frac{\tilde{T}}{T}$.

Buildings with flexible lateral-resisting systems (like frames) will benefit of bigger damping because of higher ductility demand coefficient $\mu$. The low-ductile (ordinary shear walls) that should support dynamic forces shows a low damping ratio even with higher flexible periods.

The Fig.3 is considered for indicative purposes only.

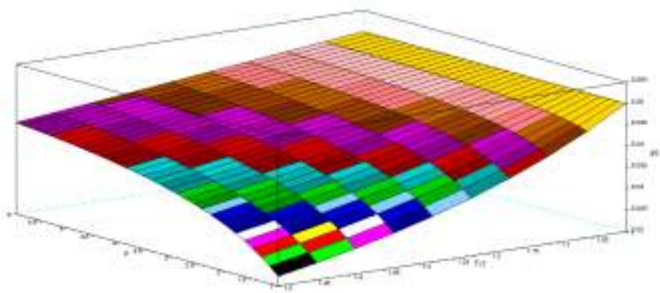

*Fig.3: Curve of* $\beta_0$ *as a function of* $\mu$ *and* $\frac{\tilde{T}}{T}$

Two numerical validations were done using the software: Robot Structural Analysis 2019. The first one is a standard (in dimensions) building (fig. 4) and the second one is a tower (fig. 5).

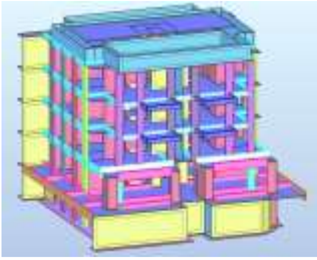

*Fig.4: Standard building*

*Fig.5: Tower*

The mentioned formulas above were applied on the models and the following results obtained:

- **For the standard building :**

No large reduction in load impact were observed due to soil parameters (described in the geotechnical report as a rocky soil) that are rigid and similar to fixed and pinned supports provided in the software's library.

**Table 1: Base shear of the rigid base model**

| Node/Case | FX (kN) | FY (kN) | FZ (kN) | MX (kNm) | MY (kNm) | MZ (kNm) |
|---|---|---|---|---|---|---|
| Case 9 (C) (CQC) | 1*X 1*Y 1*Z | | | | | |
| Sum of val. | 5925.94 | 5522.29 | 24453.51 | 293.99 | 43.43 | 2.51 |
| Sum of reac. | 4272.66 | 4757.34 | 854.41 | 62287.63 | 51607.37 | 26204.45 |
| Sum of forc. | 4272.23 | 4757.37 | 855.43 | 62288.38 | 51609.50 | 26205.82 |
| Check val. | 8544.89 | 9514.71 | 1709.84 | 124576.01 | 103216.87 | 52410.27 |
| Precision | 1.61387e-02 | 6.60590e-02 | | | | |

**Table 2: Base shear of the flexible base model**

| Node/Case | FX (kN) | FY (kN) | FZ (kN) | MX (kNm) | MY (kNm) | MZ (kNm) |
|---|---|---|---|---|---|---|
| Case 9 (C) (CQC) | 1*X 1*Y 1*Z | | | | | |
| Sum of val. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sum of reac. | 4154.95 | 4729.44 | 1167.01 | 60982.47 | 54798.08 | 30005.93 |
| Sum of forc. | 4156.26 | 4729.62 | 1166.90 | 60982.63 | 54795.35 | 30005.96 |
| Check val. | 8311.22 | 9459.05 | 2333.91 | 121965.10 | 109593.43 | 60011.88 |
| Precision | 1.62805e-01 | 2.44255e-02 | | | | |

**Table 3: Summary of base shear reduction for the standard building**

| X direction | Y direction |
|---|---|
| $100\% - \left(\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}\right)_{dir.X} = 100 - 97.2 = 2.76\%$ | $100\% - \left(\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}\right)_{dir.Y} = 100 - 100 = 0\%$ |
| $100\% - RRS_{bsa,dir\,X} = 100 - 99.5 = 0.5\%$ | $100\% - RRS_{bsa,dir\,Y} = 100 - 98.9 = 1.1\%$ |
| No embedment effects for this direction. | $100\% - RRS_e = 100 - 99.8 = 0.2\%$ |
| % reduction=3.26% | % reduction=1.3% |

For this building no major influence of the soil response to building's loading is observed then no reduction in costs will be either. Moreover, the process of construction will remain unchanged because of unchanged material's quantities.

- **For the Tower :**

Significate changes occurred between the two models made for the tower (with rigid base and flexible one).

**Table 4: Base shear of the rigid base model**

| Node/Case | FX (kN) | FY (kN) | FZ (kN) | MX (kNm) | MY (kNm) | MZ (kNm) |
|---|---|---|---|---|---|---|
| Case 7 (C) (CQC) | 1 * X 1 * Y | | | | | |
| Sum of val. | 25302.32 | 25309.57 | 129233.19 | 0.01 | 0.01 | 0.00 |
| Sum of reac. | 17932.35 | 21367.70 | 0.00 | 908618.69 | 776170.45 | 278356.88 |
| Sum of forc. | 17934.89 | 21368.18 | 0.0 | 908626.62 | 776177.87 | 278358.02 |
| Check val. | 35867.24 | 42735.88 | 0.00 | 1817245.31 | 1552348.31 | 556714.90 |
| Precision | 5.34568e-03 | 4.31381e-04 | | | | |

**Table 5: Base shear of the flexible base model**

| Node/Case | FX (kN) | FY (kN) | FZ (kN) | MX (kNm) | MY (kNm) | MZ (kNm) |
|---|---|---|---|---|---|---|
| | | | | | | |
| Case 7 (C) (CQC) | 1 * X 1 * Y | | | | | |
| Sum of val. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sum of reac. | 14531.39 | 16205.50 | 0.00 | 691218.52 | 537307.12 | 243832.55 |
| Sum of forc. | 14534.97 | 16206.21 | 0.0 | 691236.64 | 537314.98 | 243847.33 |
| Check val. | 29066.36 | 32411.70 | 0.00 | 1382455.16 | 1074622.10 | 487679.88 |
| Precision | 4.88964e-02 | 7.90681e-05 | | | | |

**Table 6: Summary of base shear reduction for the standard building**

| X direction | Y direction |
|---|---|
| $100\% - \left(\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}\right)_{dir,X} = 19.4\% > 100\% - \alpha = 16.7\%$ | $100\% - \left(\frac{\frac{\widetilde{C_S}}{B_{SSI}}}{C_S}\right)_{dir,Y} = 33.1\% > 100\% - \alpha = 16.7\%$ |
| $100\% - RRS_{bsa,dir\,X} = 100 - 100 = 0\%$ | $100\% - RRS_{bsa,dir\,Y} = 100 - 98.9 = 1.1\%$ |
| $100\% - RRS_{e,\,dir\,X} = 100 - 99.8 = 0.2\%$ | $100\% - RRS_{bsa,dir\,Y} = 100 - 100 = 0\%$ |
| % reduction=16.9% | % reduction=16.9% |

It is clear that the reduction of 16.9% in the designed base shear due to a dynamic impact will help to reduce the cost of the project which is of major influence for such big scale projects, and by this it will offer the opportunity to reduce the time of execution and will provide a better organization of the construction site.

**Conclusion:** A step to step procedure were done and could be used during the technical design of a project, to consider the effect of dynamic and static loads on a building with an influence on the organizational sequencing. Then, the sensitivity study gave the opportunity to generate a new formula, for the horizontal stiffness of springs used at the base of the structure, this formula has allowable results and are covered by code's requirements. Finally, a verification of the procedure and formula were done on two different projects with different conditions. These two project showed that this procedure influence more big scale project than small ones. However, soil parameters had a major impact on the results and further studies may be done to obtain a more accurate point of view on the influence of different loading cases on engineering projects.

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***О.А. Тугай, Тоні Самаха***

***Визначення впливу навантаження на будівлії для подальшого оптимального вибору організаційно технологічного рішення будівельного проекту***

*Даний документ допомагає визначити вплив навантажень на будівлі для подальшого оптимального вибору організаційно-технологічного рішення будівельного проекту.*

*У подальших дослідженнях показано, що вплив навантажень є верішальним у процесі будівництва, оптимізації часу та коштів. Відомі літератури описують навантаження як статистичну змінну, яка пов'язана з місцевими, екологічними та придатними для використання умовами проекту.*

*Всі види навантажень, статичні і динамічні, безпосередньо знижують або збільшують вартість проекту, це залежить від врахування, прийнятого при проектуванні. Наприклад, основною змінною, яка буде розглянута в цьому документі, є вплив грунту на вартість конструкції при статичних і динамічних навантаженнях, враховується це чи не враховується при проектуванні надбудови, і як вона змінює всю поведінку будь-якої конструкції, роблячи її більш жорсткою або більш гнучкою.*

*У цьому документі зроблено конкретне дослідження, що показує вплив ґрунту на дві різні будівлі під час динамічного впливу (сейсмічна подія в нашому випадку). Крім того, цей документ надає необхідні формули та інструменти для опису ґрунтового матеріалу в програмах для 3D-проектування. Використання цих інструментів дозволить проектувальнику конструкції змінити криву спектрів відгуку і зменшити вплив динамічного навантаження на будівлю.*

*Таким чином, порівняльна таблиця покаже різницю між використанням жорстких і гнучких базових моделей для освітлення впливу грунту. Крім того, проводиться дослідження чутливості деяких формул, що показує їх внесок у розгляд ґрунту.*

*Зменшення зсуву бази дозволить клієнту і будівельній компанії скоротити бюджет проекту, і за рахунок цього, можна буде провести оптимізацію часу будівництва.*

***Ключові слова: вплив навантаження, організаційно-технологічне рішення, оптимізація, економічна ефективність, взаємодія структури ґрунту, статичне навантаження, динамічне навантаження.***

***Посилання на статтю***

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