FACULTY OF MECHANICAL AND CIVIL ENGINEERING
IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC

XI TRIENNIAL
INTERNATIONAL CONFERENCE

HEAVY MACHINERY
HM 2023

Proceedings

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UNIVERSITY OF KRAGUJEVAC
KRALJEVO – SERBIA

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Static analysis of the RC multi-storey building depending on model and soil parameters

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The following paper contains a static analysis reinforced concrete multistorey building with flooring P+5 residential and business purposes. The building is designed as a reinforced concrete frame structure consisting of beams and columns of the same cross-section on all floors. The ground floor, which will be used for business purposes, is designed with reinforced concrete walls on the brim of the structure. The base of the building has rectangular cross-section dimensions of 15x25m, with a basic span construction of 5 m. Analysis of all relevant loads which are acting on the structure was considered according to Eurocode standards.

In the paper, the bending moments of the fundamental slab are analyzed with special emphasis on the on interaction analysis of the fundamental slab and soil which is modeled as a half-space. For such a model are given the dependence of the bending moments on the dimensions of the half-space by which the soil is represented and the characteristics of the soil itself, which are given by different deformation modules. For structure analysis software Tower 8 was used..

Keywords: static analysis of structure, half-space, foundation, fundamental slab, concrete structures, multi-storey building, geomechanics

1. INTRODUCTION

The need for population migration is a phenomenon that has existed for as long as the human species. Due to the search for better living conditions in the last ten years, an increase in the number of inhabitants can be observed in areas with better economic development. This led o the concentration of a large number of people in a small space, so there was a need to build buildings in urban areas. The buildings most often built in such conditions [7] are residential and business multi-story buildings.

The analysis of static influences was done for a multi-story reinforced concrete building (RC building) with flooring *Gf+5*, where the ground floor will be used as an office space and the typical floor levels are purposed for collective housing.

The physical and mechanical properties of the soil [1] and other data necessary for the next phase of the design process are obtained based on the geomechanical investigations [3] carried out before the start of the design process. The load applied to the structure is determined according to the Eurocode (EC) recommendations. For such determined load values, a static calculation was made in the case when the fundamental slab rests on the ground modeled as a half-space. The static influences in the elements of the RC multi-story building are analyzed with special consideration to the soil model, which is shown as a half-space of different sizes and characteristics of the soil.

2. TECHNICAL CHARACTERISTICS OF THE BUILDING

The RC multi-storey building is designed as a skeleton structure with frames in two vertical directions. The basic grid of the construction is 5m, and the layout of structural elements is shown in Figure 1.

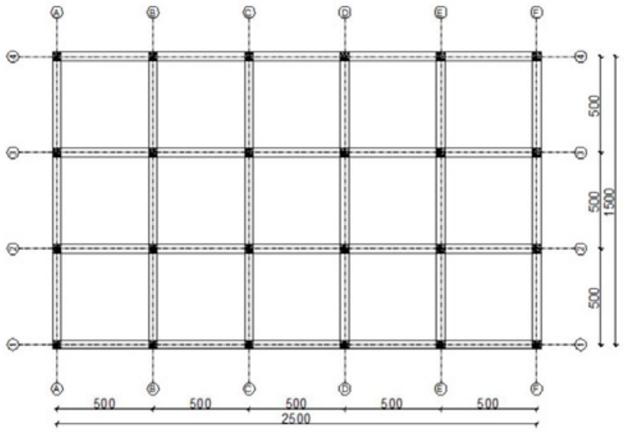

Figure 1: Disposition of structural elements of a RC building

Typical stories are rectangular bases measuring 15x25 m, the structural elements that make up the frame are columns with a square cross-section measuring 45x45 cm and beams with a rectangular cross-section measuring 30x45 cm. In addition to linear elements, the ground floor is reinforced with RC walls around the perimeter of the building. The reinforcement plan of the basic structural elements is shown in Figure 2.

The building consists of 6 floors whose floor heights are equal and amount to 2.8 m. The mezzanine structures are designed as reinforced concrete slabs with a thickness of 16 cm. The load is transferred from the roof over the floor to the soil across a foundation slab thick 45 cm, whose strength increased is with reinforced concrete beams [2]. A solution in the form of a flat impassable roof is planned for the roof construction of the building. Class C30/37 concrete and ribbed reinforcement B500B are intended to be used for the building of all RC elements of the multi-story building. The section on the long side of the structure is shown in Figure 3.

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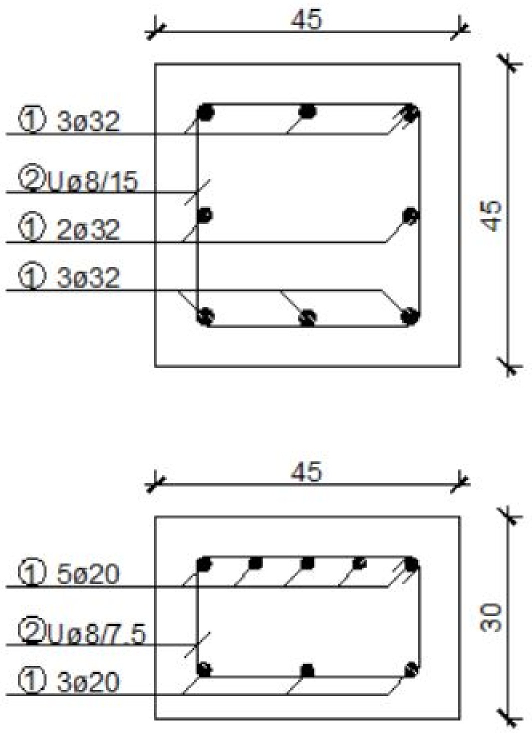

Figure 2: Beam and column reinforcement plan

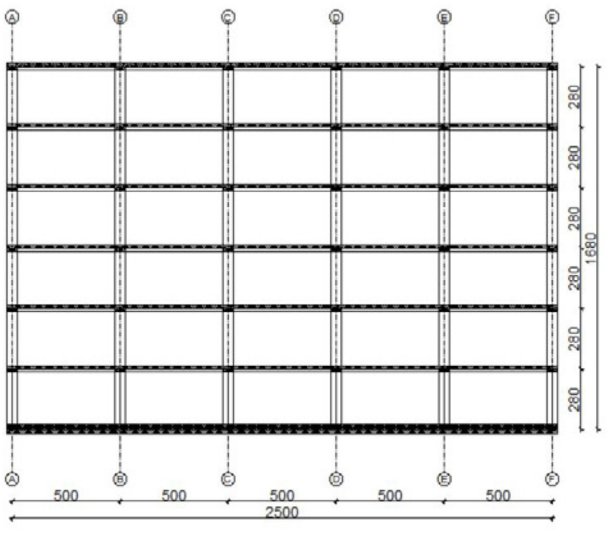

Figure 3: Vertical section of the structure

The analysis of all relevant loads that affect the construction and dimensioning of characteristic reinforced concrete elements was done according to European standards – Eurocodes.

Constructive elements of the building are dimensioned according to the effects due to permanent, snow and wind loads and seismic loads. Forms of oscillation of the structure are shown in Figure 4, Figure 5, and Figure 6.

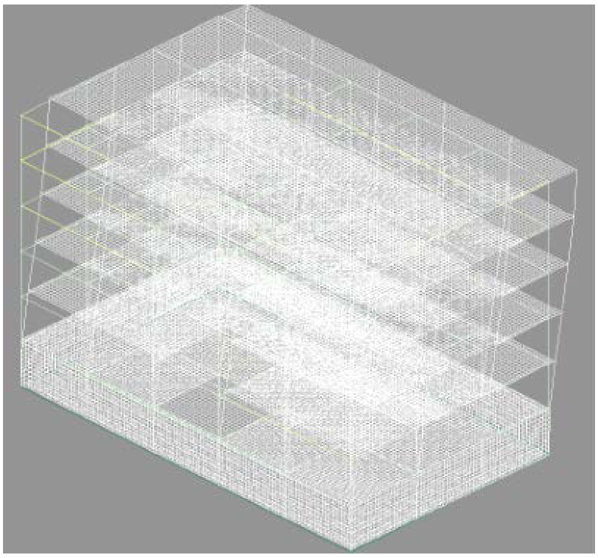

Figure 4: Form of oscillation for the first tone of the oscillation

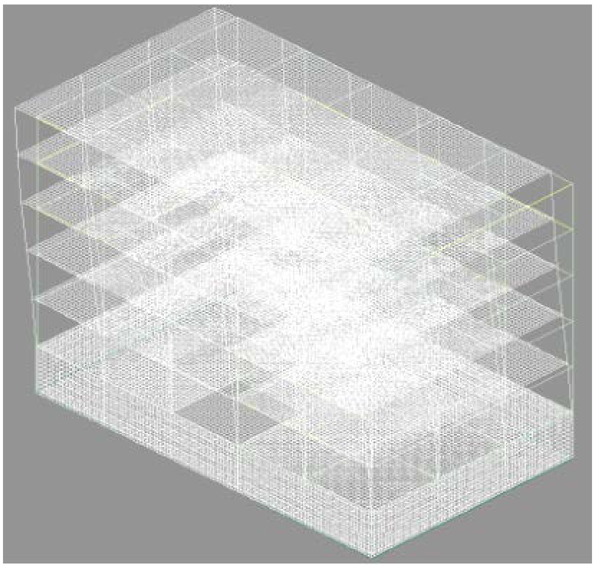

Figure 5: Form of oscillation for the second tone of the oscillation

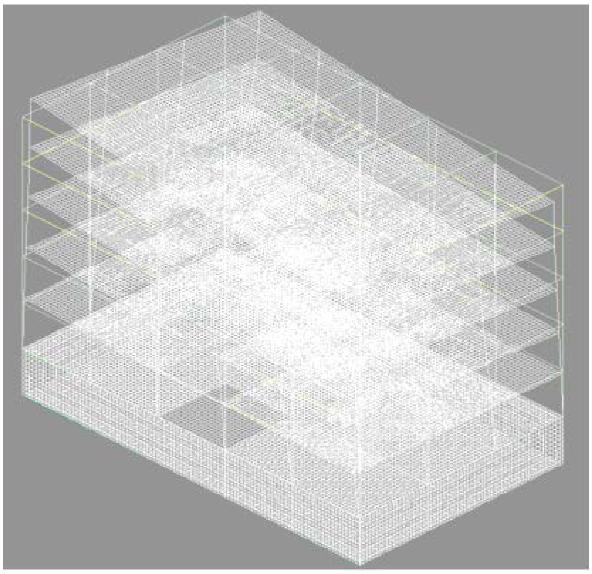

Figure 6: Form of oscillation for the third tone of the oscillation

3. MODELING OF THE CONSTRUCTION OF THE BUILDING AND THE SOIL

Modeling, calculation, and dimensioning of the structure were done in the software package "Tower 8.0", in which the calculation of static influences was done according to the linear theory of elasticity, taking into account geometric and material linearity.

3.1. Modeling of the construction of the building

For the modeling depending on the dimensions of the structural elements, linear finite elements were used (for modeling columns with dimensions 45x45 cm and beams with dimensions 45x30 cm), surface finite elements (for modeling mezzanine ceilings and external perimeter walls on the ground floor). Figure 7 shows the calculation model of the supporting elements of the structure.

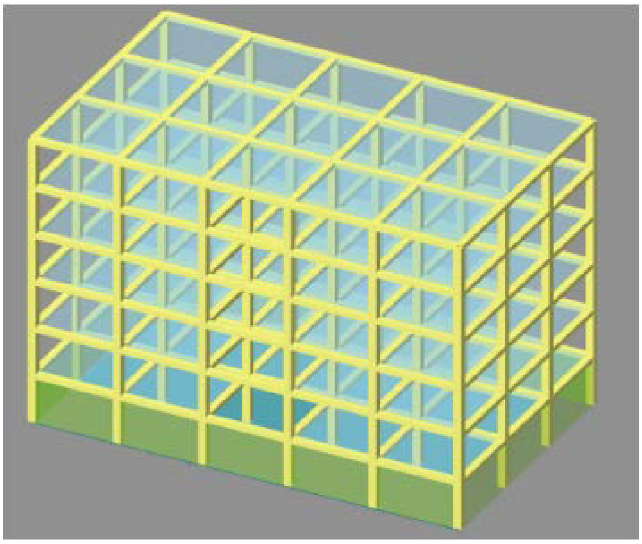

Figure 7: Model of RC construction

3.2. Modeling of the soil

The soil under the foundation slab of the RC structure is modeled as a half-space [6]. This type of soil model implies the representation of certain characteristics of the soil with volume finite elements [5], which is shown in Figure 8.

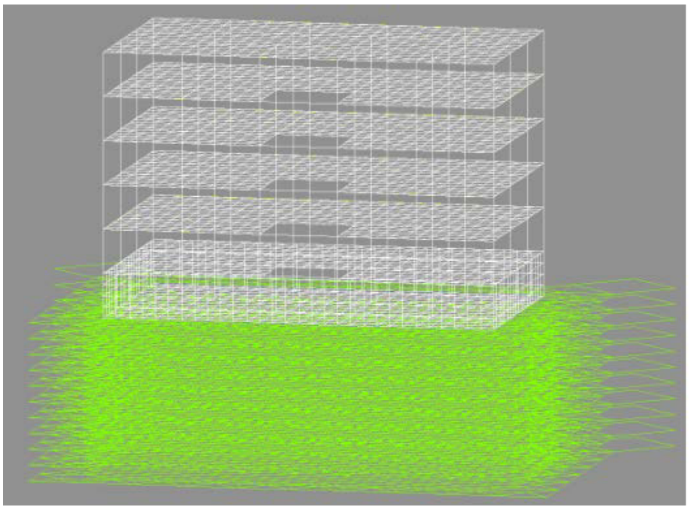

Figure 8: Model of soil under the foundation slab

The static influences were analyzed for the half-space of different dimensions - the depth of the half-space Hh in the amount of 10 m, 15 m, and 20 m and the extension beyond the dimensions of the foundation slab Hb in the amount of 3 m, 5 m, and 8 m [4].

The dimensions of the half-space need to be rationally evaluated and adopted so that the calculation model is simpler, and the obtained calculation results are sufficiently accurate.

Soil characteristics are shown by different soil deformability modules in the amount of 10 MPa, 25 MPa, and 50 MPa.

4. ANALYSIS OF THE RESULTS

In the continuation of the paper, the static influences were analyzed - bending moments M_x and M_y in the foundation slab, bending moments M_x and M_y in the section of the foundation slab, bending moments M_3 in the top of the column on the last story, stresses in the soil σ and soil settlement s for the specified cases of the soil model and soil characteristics.

The dependences of static influences are shown in relation to the size and depth of the half-space with which the soil is modeled for different values of soil deformability [8].

4.1. Static influences for the modulus of deformability *E=10 MPa*

Table 1: Maximum bending moments M_x in the foundation slab

E=10 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	382.13	382.18	414.70
	15	514.41	514.32	514.42
	20	514.12	513.90	514.06

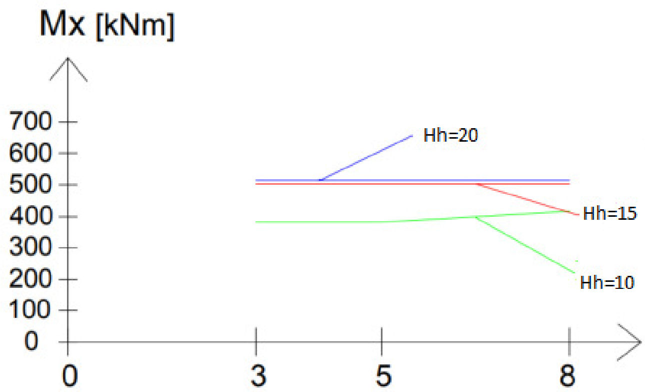

Figure 9: Maximum bending moments Mx i n the foundation slab

Table 2: Maximum bending moments M_y in the foundation slab

E=10 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	414.69	418.75	564.31
	15	565.14	573.43	574.84
	20	567.42	576.63	578.93

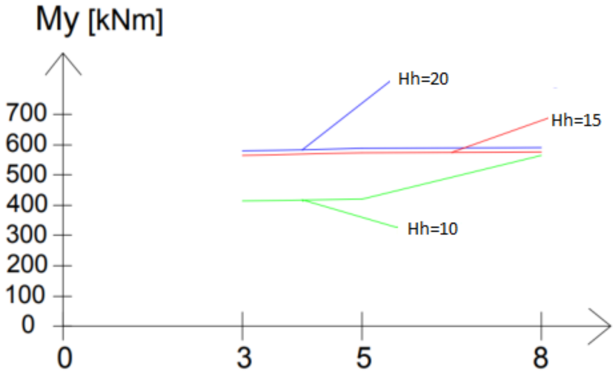

Figure 10: Maximum bending moments M_y in the foundation slab

Table 3: Maximum bending moments M_x in the section of the foundation slab

E=10 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	33.86	48.04	67.47
	15	70.37	98.94	107.01
	20	78.71	110.96	121.70

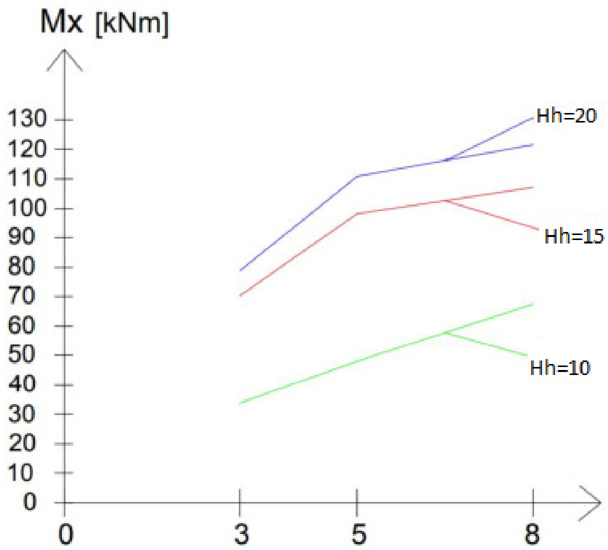

Figure 11: Maximum bending moments M_x in the section of the foundation slab

Table 4: Maximum bending moments M_y in the section of the foundation slab

E=10 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	17.43	18.49	25.25
	15	27.60	29.53	30.62
	20	29.31	31.35	32.90

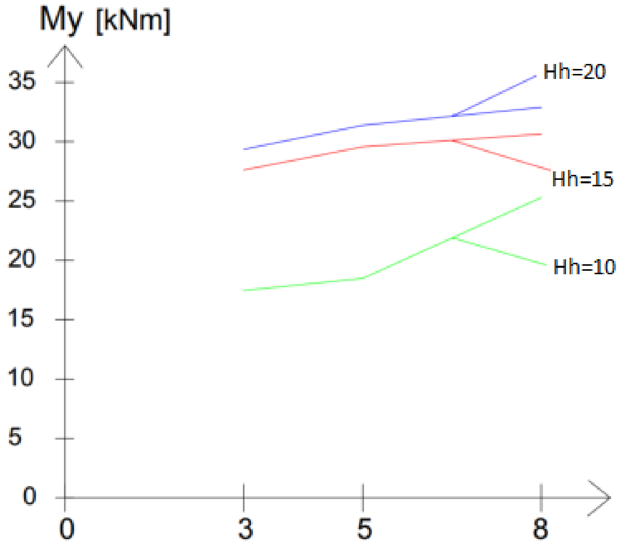

Figure 12: Maximum bending moments M_y in the section of the foundation slab

Table 5: Bending moments M_3 in the top of the column on the last story

E=10 MPa		M3 [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	154.93	158.55	207.67
	15	211.55	218.89	221.47
	20	215.31	223.59	227.19

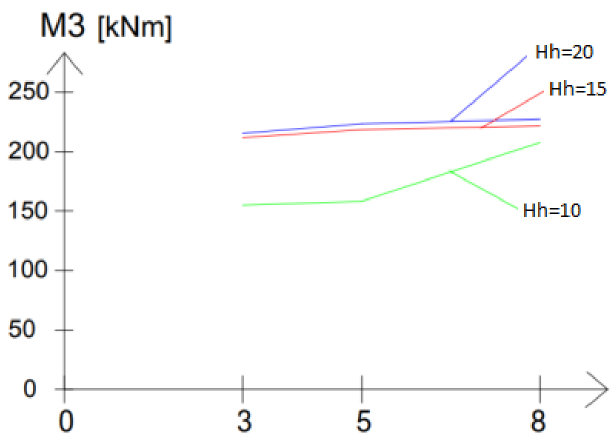

Figure 13: Bending moments M_3 in the top of the column on the last story

Table 6: Normal forces N_x in the foundation slab

E=10 MPa		Nx [kN]		
	Hb [m]	3	5	8
Hh [m]	10	4.50	4.17	5.67
	15	6.24	6.84	7.20
	20	6.38	7.54	8.07

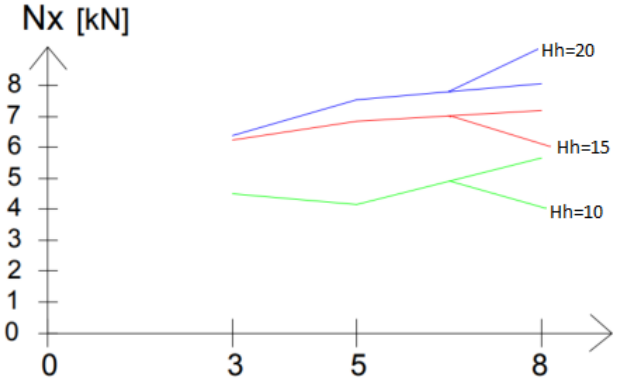

Figure 14: Normal forces N_x in the foundation slab

Table 7: Normal forces N_y in the foundation slab

E=10 MPa		Ny [kN]		
	Hb [m]	3	5	8
Hh [m]	10	4.39	4.15	5.64
	15	6.06	5.58	5.53
	20	5.99	5.56	5.55

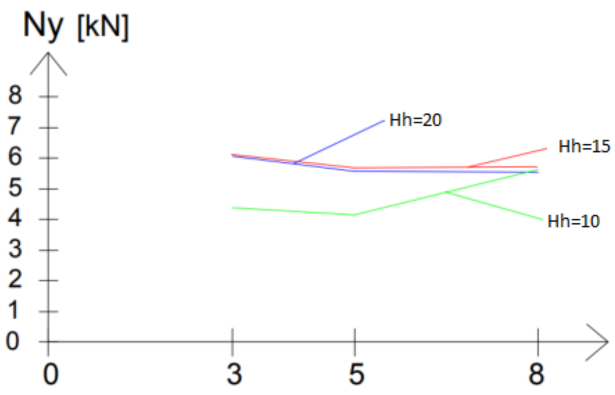

Figure 15: Normal forces N_y in the foundation slab

Table 8: Stresses in the soil σ

E=10 MPa		σ [kN/m²]		
	Hb [m]	3	5	8
Hh [m]	10	1427.48	1433.54	1933.75
	15	2141.77	2119.33	2136.42
	20	2240.35	2193.02	2217.76

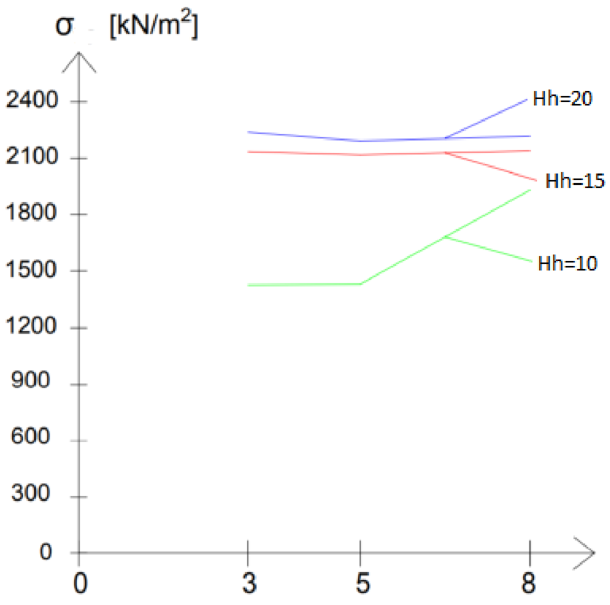

Figure 16: Stresses in the soil σ

Table 9: Soil settlement s

E=10 MPa		s [mm]		
	Hb [m]	3	5	8
Hh [m]	10	69.25	65.87	86.80
	15	123.44	110.29	102.93
	20	150.87	122.45	112.74

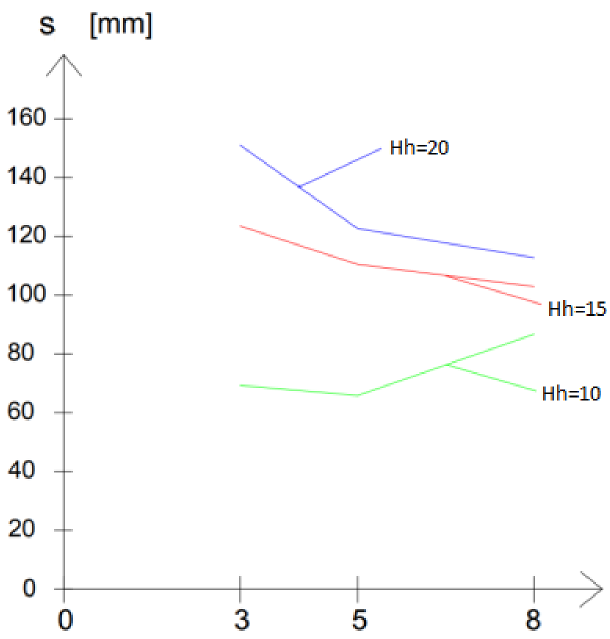

Figure 17: Soil settlement s

4.2. Static influences for the modulus of deformability *E=25 MPa*

Table 10: Maximum bending moments M_x in the foundation slab

E=25 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	379.94	380.03	511.81
	15	511.78	511.81	511.95
	20	379.94	511.60	511.82

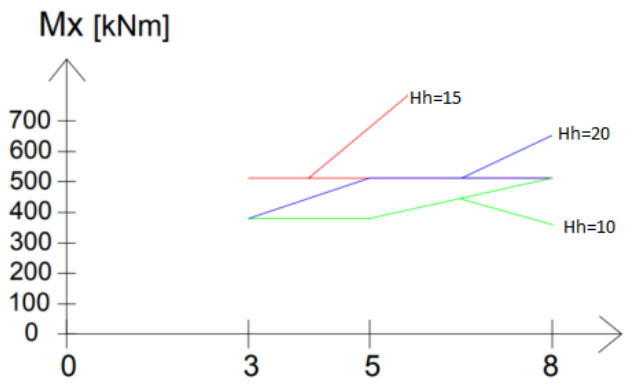

Figure 18: Maximum bending moments M_x in the foundation slab

Table 11: Maximum bending moments M_y in the foundation slab

E=25 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	405.95	409.19	551.28
	15	552.16	559.04	560.03
	20	411.30	561.85	563.49

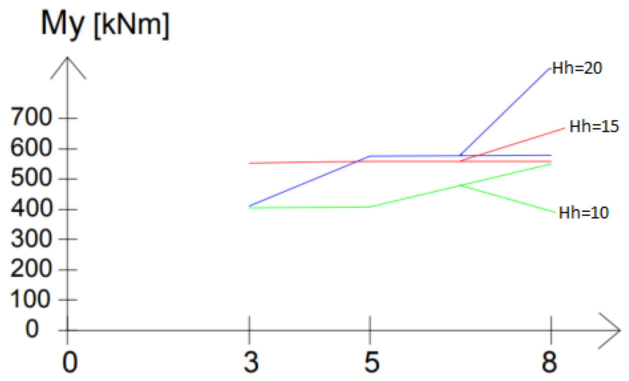

Figure 19: Maximum bending moments M_y in the foundation slab

Table 12: Maximum bending moments M_x in the section of the foundation slab

E=25 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	18.42	31.67	43.11
	15	72.23	75.55	78.94
	20	41.06	84.52	92.09

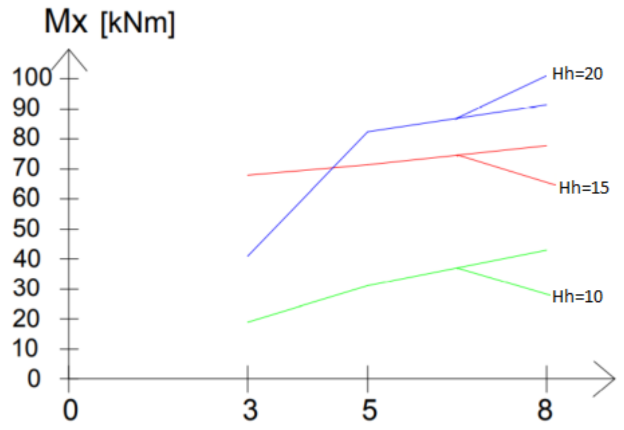

Figure 20: Maximum bending moments M_x in the section of the foundation slab

Table 13: Maximum bending moments M_y in the section of the foundation slab

E=25 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	14.21	15.64	22.08
	15	23.40	25.07	26.95
	20	16.84	26.36	27.53

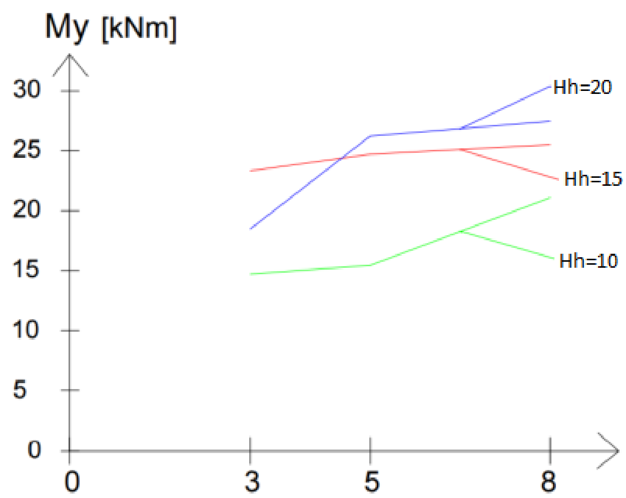

Figure 21: Maximum bending moments M_y in the section of the foundation slab

Table 14: Bending moments M_3 in the top of the column on the last story

E=25 MPa		M3 [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	151.01	151.26	197.54
	15	201.60	207.26	209.16
	20	157.11	211.37	214.13

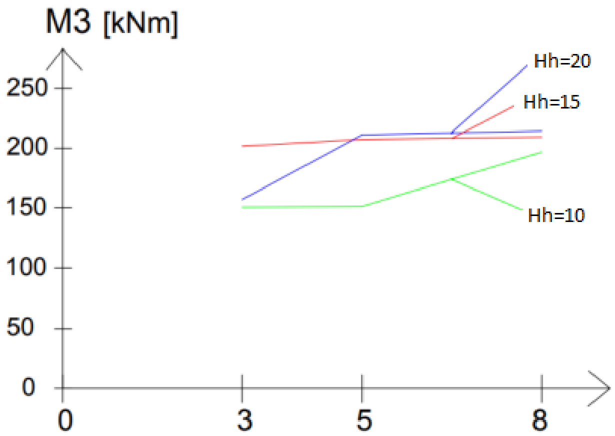

Figure 22: Bending moments M_3 in the top of the column on the last story

Table 15: Normal forces N_x in the foundation slab

E=25 MPa		Nx [kN]		
	Hb [m]	3	5	8
Hh [m]	10	4.36	4.06	5.52
	15	6.03	5.40	5.57
	20	5.52	6.07	6.23

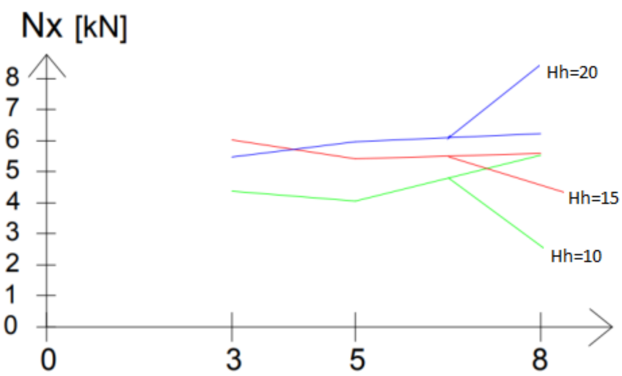

Figure 23: Normal forces N_x in the foundation slab

Table 16: Normal forces N_y in the foundation slab

E=25 MPa		Ny [kN]		
	Hb [m]	3	5	8
Hh [m]	10	4.28	4.06	5.51
	15	5.84	5.44	5.42
	20	4.38	5.42	5.40

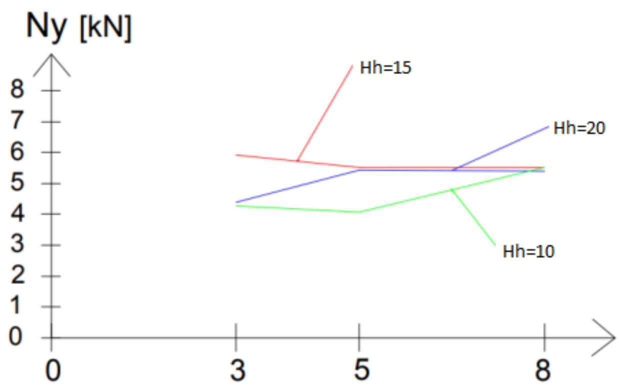

Figure 24: Normal forces N_y in the foundation slab

Table 17: Stresses in the soil σ

E=25 MPa		σ [kN/m^2]		
	Hb [m]	3	5	8
Hh [m]	10	1391.85	1395.13	1878.86
	15	2092.13	2061.56	2074.80
	20	1627.62	2136.31	2156.77

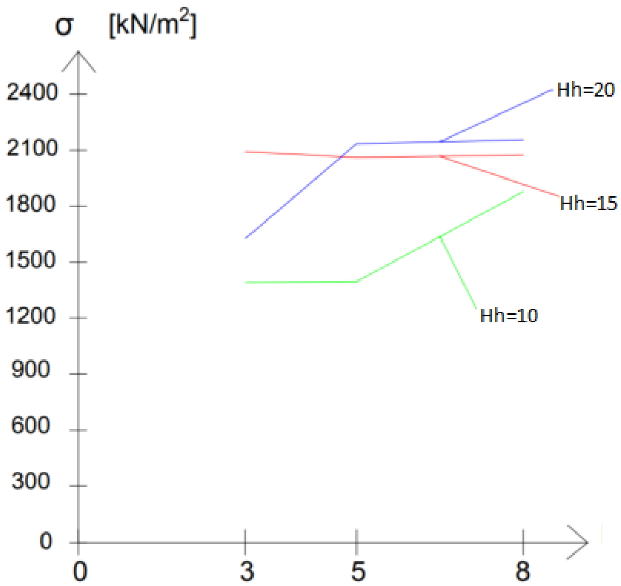

Figure 25: Stresses in the soil σ

Table 18: Soil settlement s

E=25 MPa		s [mm]		
	Hb [m]	3	5	8
Hh [m]	10	27.34	25.99	34.37
	15	48.79	43.53	40.89
	20	44.29	48.50	44.92

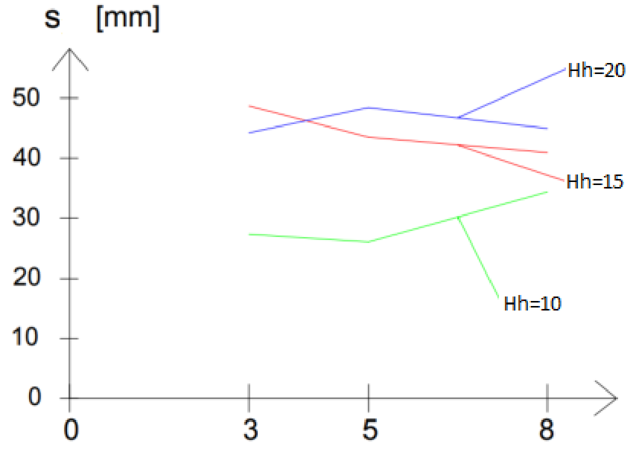

Figure 26: Soil settlement s

4.3. Static influences for the modulus of deformability *E=50 MPa*

Table 19: Maximum bending moments M_x in the foundation slab

E=50 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	505.78	505.89	505.92
	15	506.18	506.22	506.38
	20	375.91	375.87	376.06

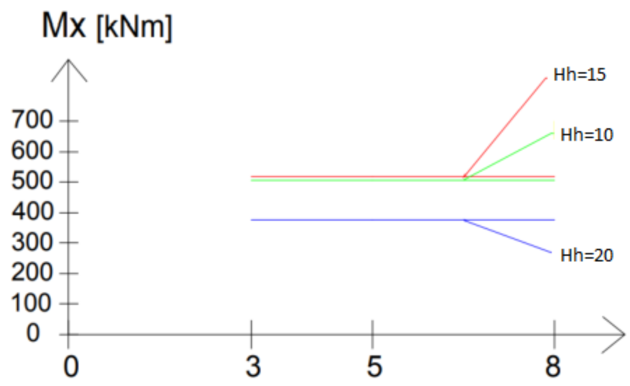

Figure 27: Maximum bending moments M_x in the foundation slab

Table 20: Maximum bending moments M_y in the foundation slab

E=50 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	532.84	536.17	536.24
	15	536.99	542.45	543.14
	20	399.70	404.42	405.30

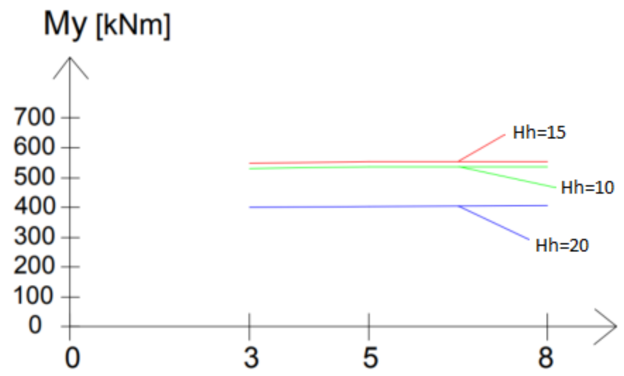

Figure 28: Maximum bending moments M_y in the foundation slab

Table 21: Maximum bending moments M_x in the section of the foundation slab

E=50 MPa		Mx [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	4.21	19.73	18.69
	15	23.28	42.41	46.55
	20	21.05	38.59	42.07

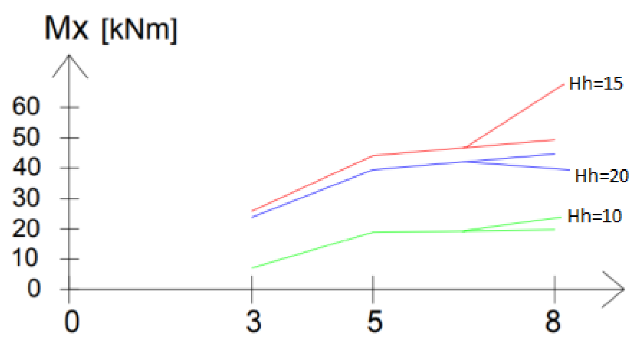

Figure 29: Maximum bending moments M_x in the section of the foundation slab

Table 22: Maximum bending moments M_y in the section of the foundation slab

E=50 MPa		My [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	16.48	17.49	17.31
	15	19.24	20.29	21.93
	20	15.60	16.42	16.97

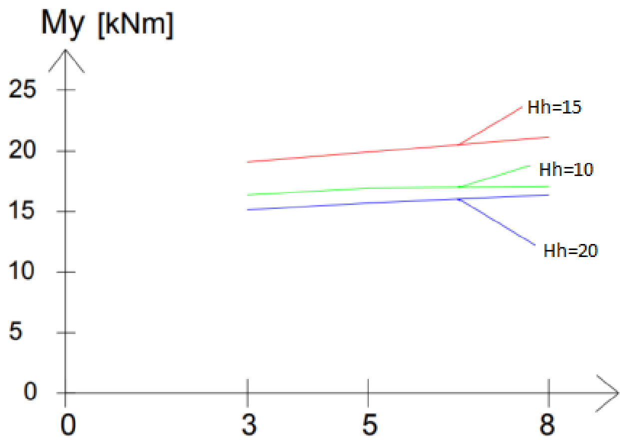

Figure 30: Maximum bending moments M_y in the section of the foundation slab

Table 23: Bending moments M3 in the top of the column on the last story

E=50 MPa		M3 [kNm]		
	Hb [m]	3	5	8
Hh [m]	10	149.36	159.15	154.37
	15	191.68	195.78	197.14
	20	184.89	187.52	187.83

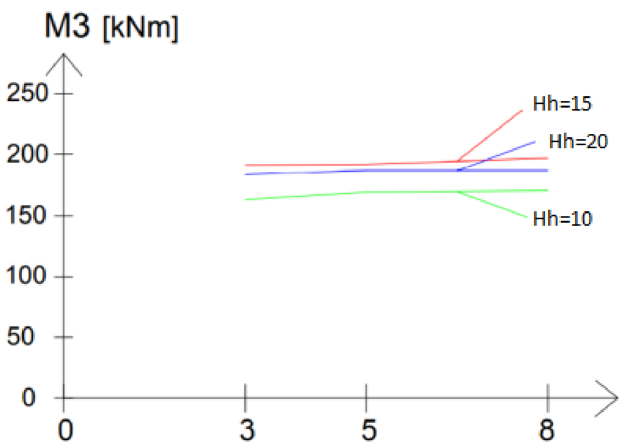

Figure 31: Bending moments M_3 in the top of the column on the last story

Table 24: Normal forces N_x in the foundation slab

E=50 MPa		Nx [kN]		
	Hb [m]	3	5	8
Hh [m]	10	5.63	5.27	5.31
	15	5.76	5.18	5.20
	20	4.37	3.85	3.85

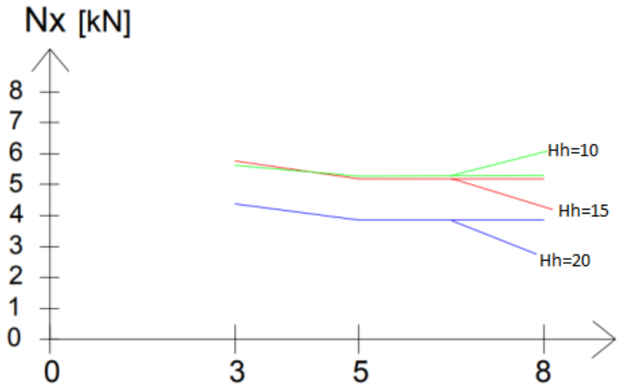

Figure 32: Normal forces N_x in the foundation slab

Table 25: Normal forces N_y in the foundation slab

E=50 MPa		Ny [kN]		
	Hb [m]	3	5	8
Hh [m]	10	5.56	5.29	5.32
	15	5.62	5.23	5.23
	20	4.22	3.89	3.86

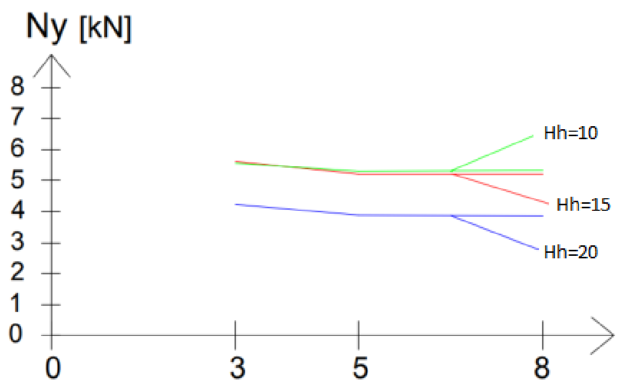

Figure 33: Normal forces N_y in the foundation slab

Table 26: Stresses in the soil σ

E=50 MPa		σ [kN/m^2]		
	Hb [m]	3	5	8
Hh [m]	10	1833.48	1834.74	1829.56
	15	2042.43	2005.85	2016.71
	20	1592.06	1541.65	1554.87

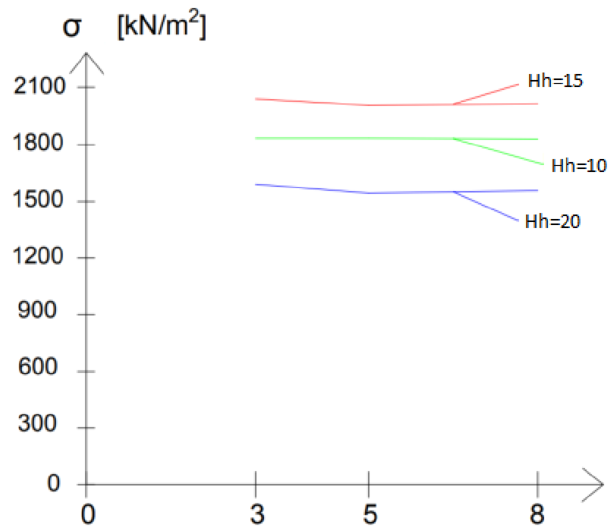

Figure 34: Stresses in the soil σ

Table 27: Soil settlement s

E=50 MPa		s [mm]		
	Hb [m]	3	5	8
Hh [m]	10	18.14	17.23	16.99
	15	24.04	21.44	20.32
	20	21.84	17.79	16.60

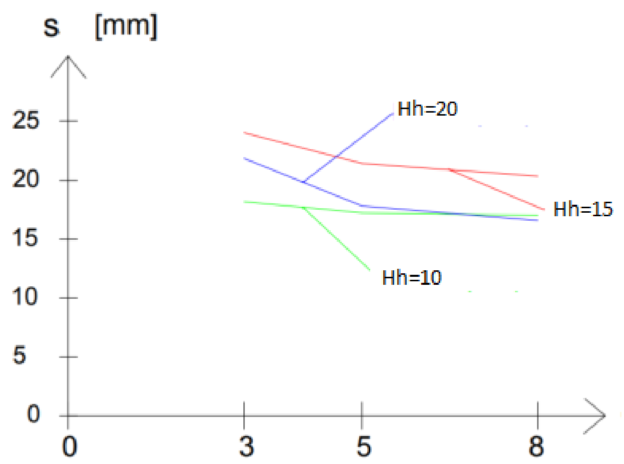

Figure 35: Soil settlement s

5. CONCLUSION

Based on the presented diagrams and tabulated values, a comparison of the static influences can be made depending on the variable parameters and the given modulus of deformability. The variable parameters are the depth of the half-space (Hh) and the dimensions of the half-space, i.e. the extension of the half-space beyond the dimensions of the fundamental slab (Hb), which is explained in the part of soil modelling [9].

5.1. Static influences for the modulus of deformability E=10 Mpa

The static influences are similar for half-space depths of 15 m and 20 m, while in the case of a half-space depth of 10 m the value static influences are lower.

5.2. Static influences for the modulus of deformability E=25 Mpa

The values of the static influences are similar for the half-space depths of 15 m and 20 m, while in the case of the half-space depth of 10 m, the values are smaller, and for *Hb* of 5m and 8m. For *Hb* of the 3m the values are significantly different, so it is not possible to assess the dependence of static influences.

5.3. Static influences for the modulus of deformability E=50 Mpa

The values of static influences (bending moments and normal forces) are similar for the half-space depths of 10m and 15m, while for the half-space depth of 20m, the values are slightly lower. With the increase in *Hb*, the values of static influences generally decrease. The values of the moments at the top of the column are similar for the half-space depths of 15m and 20m, while the values for the half-space depth of 10m are slightly lower.

Based on these values, it is necessary to estimate with which value the depth of the half-space and the extension over the dimensions of the base plate to model the soil. For the presented case, the most optimal solution would be to adopt a half-space depth of 15m and an extension length of 5m.

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