Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

MODELING THE STRUCTURAL BEHAVIOR OF A CNC BEARING MEMBER SUBJECTED TO STATIC AND DYNAMIC LOADS

Nicoleta-Adaciza IONESCU[1], Daniela DOBRE[1, 2], Claudiu-Sorin DRAGOMIR[1, 3]

[1]National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development - URBAN-INCERC, 266 Pantelimon Road, District 2, Bucharest, Romania
[2]Technical University of Civil Engineering of Bucharest, 124 Lacul Tei Blvd, District 2, Bucharest, Romania
[3]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: adaionescu2002@yahoo.co.uk

Abstract

The paper aims within a multidisciplinary approach (Chemistry, Engineering, Finite element analysis) to highlight the structural behaviour of a computer numerical control (CNC) resistance element from the vibrations point of view and following the deformations and efforts arising from static and dynamic loads. The modelling of the structural bearing member was done with the Finite Element Method, using three-dimensional elements of the Solid type, in specialized software, and considering different types of material (cast iron, reinforced concrete and reinforced concrete with the addition of polymer-coated clinker). Results concerning the variation of the dynamic characteristics (natural periods of vibration) and response spectra in accelerations, velocities and displacements in several points are presented. In conclusion, with regard to the considered materials, the use of concrete with intelligent addition to build the base of a CNC is a good solution. Using a smart reinforced concrete material embedded in the metal box gives greater rigidity to the structural system, the fundamental period having the lowest value, compared to the other two cases.

Key words: *concrete, self-repair, modelling, static and dynamic loads.*

INTRODUCTION

The support system plays an important role in the correct operation of a numerically controlled (CNC) machine tool because it must ensure stability in the case of a high level of vibrations (vibrations produced within the manufacturing process) and following deformations and structural efforts arising from different types of loads (static, dynamic), Figure 1.

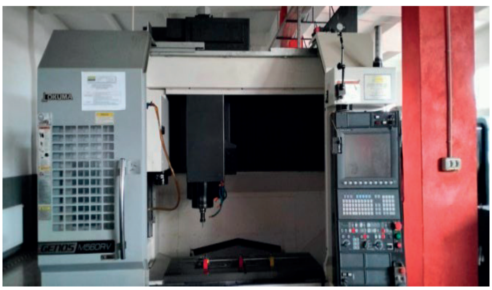

Figure 1. Image of a Computer Numerical Control (CNC) Machine Tool

In order to have a bed structure for a CNC machine tool with a corresponding rigidity as high as possible, it is usually built from cast iron, but in the case of the modelling presented in this work concrete will also be used as a construction material. The considered concrete will have an addition (made of clinker coated with polymer) that improves to a certain extent its properties regarding the density-settlement relationship and the resistance to compression and bending. In addition, this concrete has self-repair properties for a certain area of cracking, thus extending the service life of the concrete.

The concept of self-repair in the case of cementitious materials is fundamentally related to the state of cracking - microcracks in the structure of the material, as a form of inducing degradation in the mass of the material. The self-healing effect is realized by closing the cracks, sealing them, partially or completely.

Most of the time, the recovery initiated is not only at the physical level, related to the microstructure of the material, but also to its functionality, to the recovery of the initial mechanical characteristics (Zapciu et al., 2021; Voinitchi et al., 2020).

MATERIALS AND METHODS

The finite element analysis carried out is aimed at understanding the behaviour of a structural element (of type support CNC) considering as construction materials for it cast iron, concrete with addition (clinker covered with polymer) and concrete with addition and cast-iron coating. The composition of the cement concrete was developed, according to CP 012-1:2007, depending on the concrete exposure classes. When establishing the concrete recipe, the amount of cement and the water-cement ratio were determined, as well as the amounts of aggregates required. Depending on the granularity of the aggregates, the percentages per granularity class were determined so that they fall within the favourable granularity area of the normative. Tables 1 to 5 are presented comparative the characteristics of cement concrete of class C30/37 with concrete prepared with smart addition of class C30/37.

The degree of crack healing was evaluated on controlled cracked concrete test pieces using a chloride electromigration experiment under the action of an electric field. The degree of repair being the ratio of the relative decrease in current due to the contribution of the crack in the material with smart addition and the classic preparation.

As results presented and discussed will be mainly the dynamic structural characteristics of the CNC machine tool bed structure depending on the material used.

It should be specified that in the case of the modelled CNC machine tool bed structure (with the geometric dimensions of an existing one) there are no known normative provisions that would impose restrictions on the number and maximum value of static and/or dynamic loads, the maximum values of deformations, different safety coefficients (to buckling, breaking or fatigue), minimal execution, assembly or exploitation imperfections, vibration frequencies, rate of deformation in stationary plastic flow, product life, weight, material and moments of inertia, stiffness at different demands, static and/or dynamic stability, behaviour under different simultaneous loads etc.

Table 1. The compositions of cement concrete and cement concrete with intelligent addition

Component	Concrete (B)	Concrete with intelligent admixture (BAI)
Cement CEM I42.5	450	450
Water	200	200
Air	0	0
Superplasticizer additive	3	3
Aggregate dosages of ballast	1672	1497
Smart addition (polymer coated clinker)	0	200

Table 2. Results of density and settlement determinations for concrete

Sample code	Settling (mm)	Density (kg/m^3)
B	140	2330
BAI	80	2350

Table 3. Results of compressive and flexural strength determinations

Sample code	f_{c7} N/mm^2	f_{c28} N/mm^2	f_{inc7} N/mm^2	f_{inc28} N/mm^2
B	33.8	43.2	4.52	5.34
BAI	35.1	45.7	4.61	5.95

Table 4. Test results for resistance to water penetration under pressure

Sample code	Penetration depth (mm)
B	14
BAI	12

Table 5. Degree of healing after 3 days for cracked and re-cracked self-healing concrete

Concrete condition	Cracked	Re-cracked
Degree of healing after 3 days GV3, %	23.0	14.4

In order to reach the final model for the presented bed structure, the following stages were taken into account:

- the transition from the physical system to a structural model;
- the transition from an infinite number of degrees of freedom to a finite number (situation specific to the mesh grid).

Finite element characteristics are related to 3D finite element dimensions, nodes (identifies the

Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

geometry of the model), degrees of freedom (possible values that the kinematic quantities in the nodes can take), forces applied directly in the nodes. Thus, static force is 18kN, distributed in the nodes of the network on an associated surface, and the dynamic force from the vibrations of the CNC attached to the modelled bed structure is of Time-history type for a certain velocity – RPM = 60/T, for 1200 rpm, T = 0.05 s the input period.

– constitutive properties: isotropic material with linear elastic behaviour, longitudinal/ transversely modulus of elasticity (E or G), Poisson's ratio;

Modulus of elasticity $E_{BAI} = 2.5 \times 10^7$ kN/m^2, $E_{Cast\ iron} = 115 \times 10^5$ kN/m^2; Specific weight$_{BAI}$ = 23.5 kN/m^3; Specific weight$_{cast\ iron}$ = 72.5 kN/m^3.

– the solution of the system of equations numerically obtained by the software etc.

In this case, three-dimensional elements of the Solid type were used, with 8 nodes and 6 quadrilateral faces with one joint at each node, Figure 2. This type of element was chosen because the dimensions of bed structure are comparable (there is no negligible dimension in the comparison with the others), this element being able to capture a three-dimensional stress state.

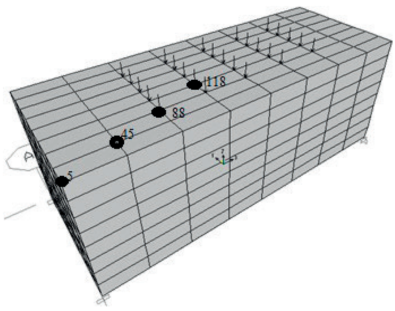

Figure 2. Real dimensions for bed structure of machine tool: 1.321 m x 0.508 m x 0.500 m. The position of the considered nodes (points 5, 45, 88, 118)

RESULTS AND DISCUSSIONS

Table 6 highlights the fact that the use of the BAI material embedded in the metal casing confers greater rigidity to the structural system, the fundamental natural period having the lowest value, compared to the other two cases. For the higher modes, however, the system is more rigid if it is made of BAI without inclusion in cast iron. It should be specified that the inclusion was made by modelling the shell as a three-dimensional solid structural element of the Shell type, which incorporates both functions, the membrane and the plate (with a thickness of 0.2 m). The results will differ if the thickness of the cast iron casing is changed.

Table 6. The variation of the dynamic characteristics depending on the material used (embedment type support in 4 nodes/support points)

Material for structural system	Dynamic characteristics/ periods of vibration [s]
Cast iron	T1 = 0.04964 T2 = 0.03291 T3 = 0.02944 T4 = 0.01603
Concrete with intelligent addition	T1 = 0.03264 T2 = 0.02108 T3 = 0.01883 T4 = 0.01005
Concrete with intelligent addition in the metal casing (cast iron)	T1 = 0.03123 T2 = 0.02564 T3 = 0.02503 T4 = 0.01313

Figures 3a, 3b, 3c and 3d point out the first 4 modes of vibration, not for all 3 considered materials (embedment-type support on the contour, perimetral support points).

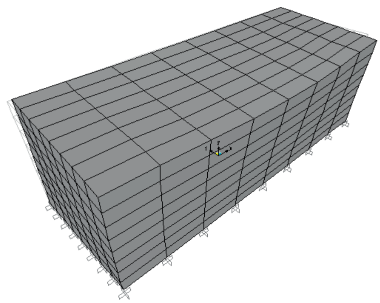

Figure 3a. Fundamental vibration mode, T_1 = 0.01094s

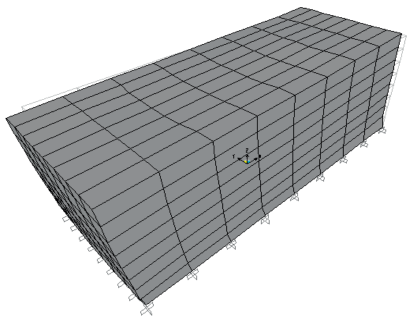

Figure 3b. Vibration mode 2, T_2 = 0.00773s

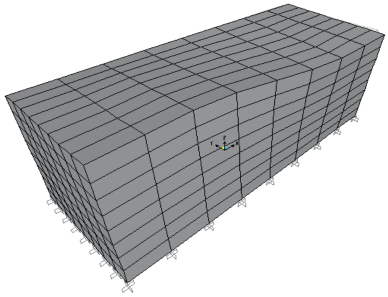

Figure 3c. Vibration mode 3, $T_3 = 0.0068$s

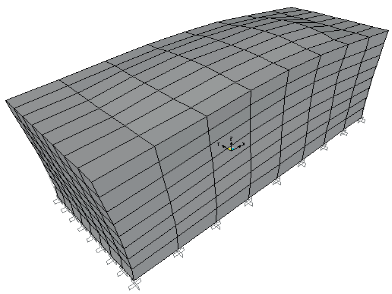

Figure 3d. Vibration mode 4, $T_4 = 0.00622$s

For the situation of a bracing type embedded in 4 nodes (support points), the representation of the vibration modes is approximately the same as the form of representation from Figure 3, but with slightly different values.

The use of BAI material embedded in the metal casing does not confer greater rigidity to the structural system of the batten compared to the second case considered, only BAI, but a better rigidity than in the case of using cast iron.

The same conclusion holds for the higher modes.

Regarding the forms of vibration considering two other materials (cast iron and BAI in the metal case), they do not differ significantly from those in Figure 4 (so that they will not be presented anymore), only the vibration periods differ, as can be seen in Table 7.

Comparatively, the variation of the values of the periods of vibration depending on the material used and the type of support, were also analysed and is found that the bed structure is a more flexible structural element when it is made of cast iron and less flexible when it is made of concrete with intelligent addition, or BAI in the metal case (depending on the type of support).

Table 7. The variation of the dynamic characteristics depending on the material used (embedment-type support on the contour/perimetral support points)

Material for structural system	Dynamic characteristics/periods of vibration [s]
Cast iron	T1 = 0.01645 T2 = 0.01179 T3 = 0.01041 T4 = 0.00934
Concrete with intelligent addition	T1 = 0.01094 T2 = 0.00773 T3 = 0.00680 T4 = 0.00622
Concrete with intelligent addition in the metal casing (cast iron)	T1 = 0.01438 T2 = 0.01134 T3 = 0.00980 T4 = 0.00921

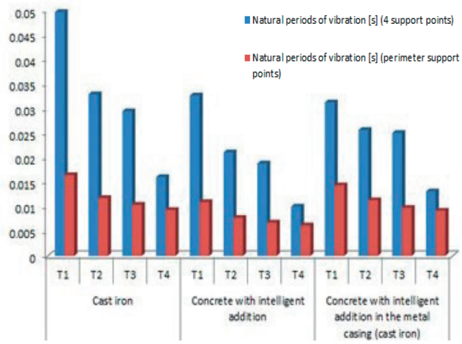

Figure 4. Relation T-Material-Support conditions

On the other hand, the dynamic response is represented by accelerations, velocities, displacements (from the dynamic action type loading), in several points considered of interest, Figures 5a-5c (embedded support in 4 nodes/support points).

The maximum values of the accelerations, velocities, displacements in the nodes considered (with values for damping of 10%, for example) have a small order of magnitude, but the graphic representation is made for the variation of the values in the 3 material situations.

In point 118, for instance, these values are higher in all cases because it is the position closest to the point of application of both static and dynamic force.

In the absence of reference/existing data in codes, standards, norms, or other studies, these values cannot be reported and commented critically.

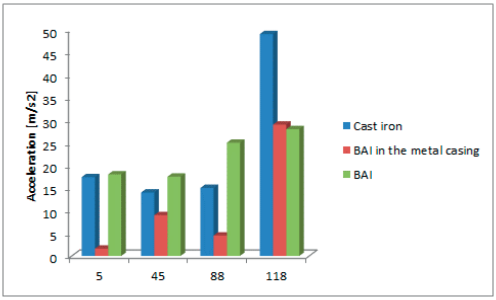

Figure 5a. The maximum values of the accelerations at the specified points, for the materials used

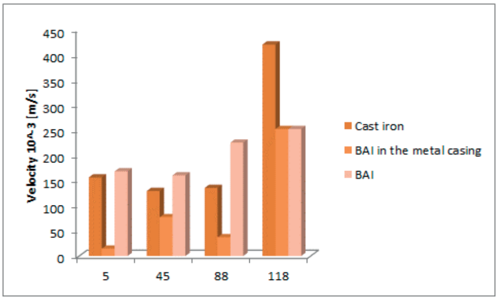

Figure 5b. Maximum velocities values in the specified points, for the materials used

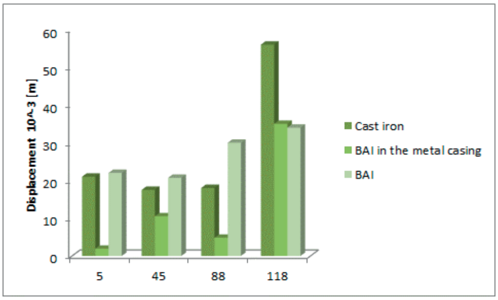

Figure 5c. The maximum values of the displacements in the specified points, for the materials used

It can also be concluded, based on the figure above, that a bed structure made of BAI with a metal casing (cast iron) will have a lower dynamic response than in the case of the other two situations, although its vibration periods were not the littlest.

The answer in terms of kinematic quantities - concrete slab with intelligent addition is presented in Figure 6 and Figure 7.

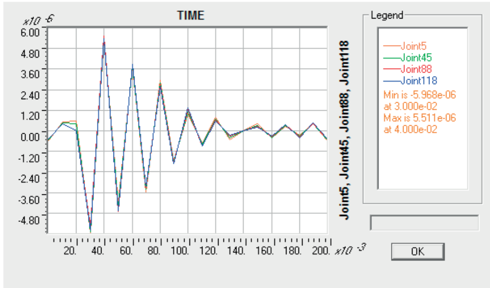

Figure 6. The variation of displacement over time, in several points on the upper surface, from dynamic action

On the other hand, the answer is also represented in terms of kinematic quantities-accelerations, velocities, displacements (from the dynamic action), in several points considered to be of interest (embedded support in 4 nodes/support points), Figure 7 (a-d).

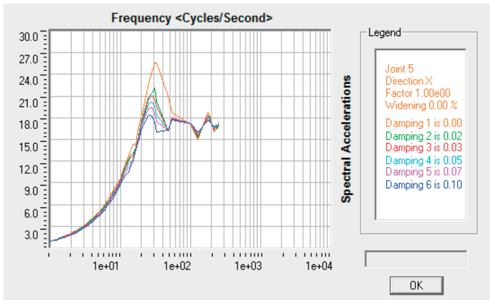

Figure 7a. Point 5

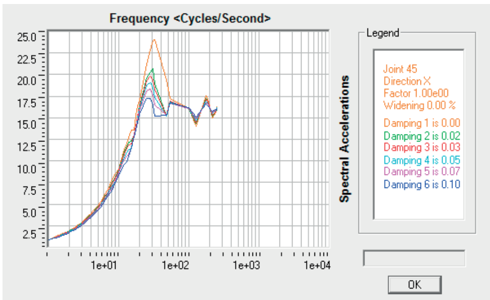

Figure 7b. Point 45

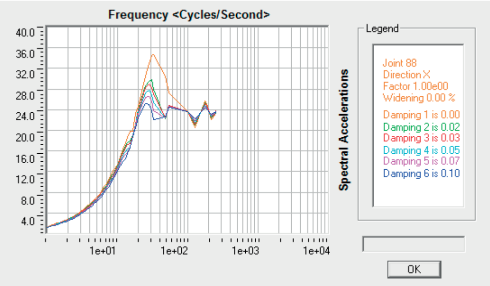

Figure 7c. Point 88

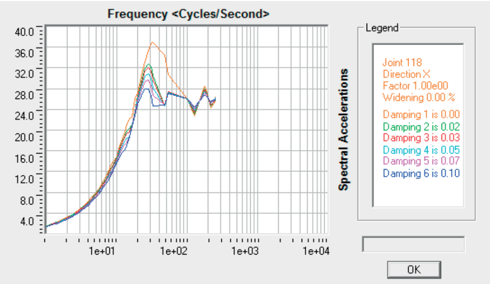

Figure 7d. Point 118

Figure 7. Spectra of response in accelerations, in certain points on the upper surface, from dynamic action

CONCLUSIONS

Concerning to the considered materials, the use of concrete with intelligent addition to build the base of a CNC is a good solution. This is also of interest because, from taking over some loads induced by the operation of the CNC, an opening of cracks of an unfavourable order of magnitude may occur, but the self-repairing capacity of the concrete will be an important element. So, it is highlighted that the use of the BAI material embedded in the metal casing confers greater rigidity to the structural system, the fundamental period having the lowest value, compared to the other two cases. For the higher modes, however, the bed structure is more rigid if it is made of BAI without inclusion in cast iron. By modelling this structural system made of 3 different materials, loaded with static and dynamic forces, in two support situations, we wanted to evaluate the behaviour of a fixed CNC part from the point of view of the dynamic characteristics (natural periods of vibration) and of some kinematic quantities - through response spectra in accelerations, velocities and displacements. Regarding the modeling method used - Finite element method (in the field of machine, equipment and installation constructions/CNC), the basic component of a system analysed by FEM is the resistance structure defined as a mechanical assembly with a very clearly established functionality, such as taking over some loads, ensuring a certain functionality, ensuring a static and/or dynamic stability, guaranteeing a rigidity imposed by the designer, etc. The article wanted a multidisciplinary approach (Chemistry, Structural Engineering, Finite Element Analysis), but which cannot be related to reference/existing data in codes, standards, norms.

ACKNOWLEDGEMENTS

This research work was carried out within PN 23 35 01 01-Integrative concept of digital analysis of data from large-scale seismic monitoring of the national territory and the built environment, intended for the rapid identification of the destructive potential of seismic events produced in Romania and in the adjacent regions.

REFERENCES

CP 012-1:2007 Concrete Production Code.

SAP2000 Integrated Software for Structural Analysis and Design, Computers and Structures Inc., Berkeley, California.

Voinitchi, C., Baeră, C., Zapciu, M., Matei, C., Szilagyi, H. (2020). Development of Cement-Based Materials Enriched with Polymeric Coated Reactive Grains as Long-Term Promoter of Matrix Continuous Hydration. *IOP Conf. Series: Materials Science and Engineering, 877*, 012028, doi:10.1088/1757-899X/877/1/012028.

Voinitchi, C., Baeră, C., Zapciu, M., Matei, C., Szilágyi, H., Ionescu, N.-A., Tudorie, F. (2020). Polymeric coated reactive grains as intelligent addition in cementitious composites for generating the self-healing effect. *Annals of the Academy of Romanian Scientists, Series on Engineering Sciences, 12*(1), ISSN 2066-8570.

Zapciu, M., Voinitchi, C., Ionescu, N.-A., Olteanu, M. (2021). New material using cement-based matrix with self-repair properties based on reactive grains with protective coating. *Studia Ubb Chemia*, *LXVI*(4), 253-265, doi:10.24193/subbchem.2021.4.18.