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A new principles for implementation and operation of foundations for machines: A review of recent advances

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Abstract. The aim of this paper is to present the most important issues on the implementation, operation and maintenance of foundation for machines. The article presents the newest solutions both in terms of technology implementation as well as materials used in construction of such structures. Foundations for machines are special building structures used to transfer loads from an operating machine to the subsoil. The purpose of these foundations is not just to transfer loads, but also to reduce vibrations occurring during operation of the machine, i.e. their damping and preventing redistribution to other elements of the building. It should be noted that foundations for machines (particularly foundations for hammers) are the most dynamically loaded building structures. For these reasons, they require precise static and dynamic calculations, accuracy in their implementation and care for them after they have been made. Therefore, the paper in detail present the guidelines regarding: design, construction and maintenance of structures of this type. Furthermore, the most important parameters and characteristics of materials used for the construction of these foundations are described. As a result of the conducted analyzes, it was found that the concrete mix, in foundations for machines, should have a low water/binder ratio. For its execution, it is necessary to use broken aggregates from igneous rocks and binders modified with mineral additives and chemical admixtures. On the other hand, the reinforcement of composites should contain a large amount of structural reinforcement to prevent shrinkage cracks.

Keywords: foundations for machines; dynamic loads; building dynamics; vibrations; reinforced concrete

1. Introduction

1.1 The problem of the occurrence of dynamic loads in building structures

In practice, building structure design frequently requires taking into account the static and dynamic loads in the calculations. Dynamic loads are all forces acting on the structure, which are characterised by variability in a short period of time in relation to the essential dynamic characteristics (a period of natural vibrations) of the loaded structure. The dynamic loads do not include loads whose variability in time is slow and lasts for hours, months or even years (e.g. rheological changes), e.g. (Gorski *et al.* 2018, Craciun 2008). Changes in parameters of dynamic load can be mechanical (e.g.: force, pressure, stress, strain, displacement) but also thermal, electrical and chemical, e.g. (Nogueira 2018, Qing *et al.* 2018, Guan *et al.* 2019).

Dynamic loads acting on engineering structures may come either from the force of nature such as wind load, earthquakes, sea waves; or from the industrial or technical human activity such as vehicle traffic on bridges and viaducts or movement of crane beams; from some machine parts during rotational or reciprocating motion; from the impacts of hammer; from the explosions in the air or in the ground (during works in quarries); from the shocks caused by the exploitation of coal deposits or during transport by road and rail (Kappos 2002). Energy from the dynamic loads can be transferred directly to the structure through any center, which can be:

- solids (structural elements, running machines),
- gas (usually air),
- liquids (usually water).

In some cases, there are also indirect means of energy transfer, which most commonly are:

- movement of the ground during earthquakes,
- ground movement from the road or rail transport.

Time-dependent dynamic loads are defined as excitation forces. All excitation forces, causing vibrations of the structure, can be divided into deterministic and non-deterministic forces. Deterministic forces include those which can be described with the help of strict mathematical relationships, e.g. centrifugal force generated by the operation of rotating machinery. Non-deterministic forces are all physical phenomena which produce excitation forces acting on structures and are random, e.g. wind speed, ground acceleration during earthquakes, etc. Such loads are inherently random and cannot be described by strict functional dependencies, but only by using statistics.

The breakdown of deterministic and random excitation forces is compiled on the basis of Cmielewski and Zembaty (1998), in Fig. 1.

Situations where it is necessary to take into account the occurrence of dynamic influences on structural elements, require a particular attention of the designer due to the fact that the loads of this type cause the occurrence of vibrations

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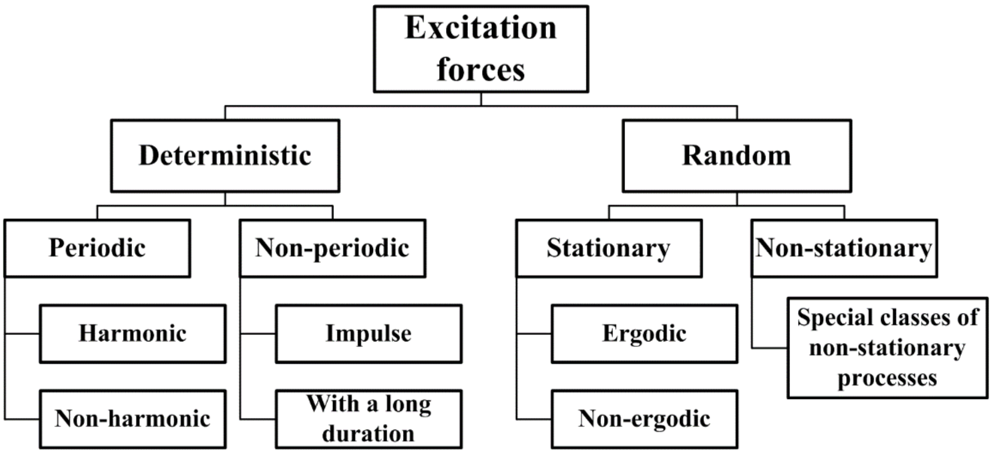

Fig. 1 Characteristic of excitation forces resulting in structure's vibrations (Cmielewski and Zembaty 1998)

in the structure. The vibrations are an inherent phenomenon accompanying buildings throughout their lifecycle, starting from the building process through maintenance up to their disposal, and usually their occurrence does not adversely affect the work of the structure.

Exceptions are situations related to the occurrence of:

- the so-called "harmful" vibrations,
- vibrations caused by variable forces, which could cause the occurrence of the so-called "resonance", (Yuan *el al.* 2016).

The work of structures subjected to the occurrence of "harmful" vibrations or resonant vibrations may in the long term results in very serious effects such as structure's damage or, in extreme cases, failure or destruction. The occurrence of defects of this type are very difficult to detect in the construction of the foundation. For their detection, the non-destructive method of acoustic emission (AE) or digital image correlation (DIC) is most often used, e.g. (Golewski and Sadowski 2016b, Gorzelanczyk *et al.* 2016, Golewski 2019, Hola *et al.* 2011). Moreover, to detect cracks in structures loaded dynamically are also used other new methods, e.g. by using regularized extreme learning machine (Kourehli *et al.* 2018) or based on the energy principle (Ren *et al.* 2018).

At this point, it should also be added that, such cracks in the material may also occur in the case of structures working in conditions of complex stress, e.g. (Aliha *et al.* 2012 2018a,b, Linul *et al.* 2017, 2019, Sadowski and Golewski 2018, Golewski 2017a, b, d, 2018a, Fakoor *et al.* 2019, Berto *et al.* 2017, Marsavina *et al.* 2017, 2015, Mirsayar *et al.* 2016, Rafiee *et al.* 2015, Taheri-Behrooz *et al.* 2018). It should be noted, however, that with properly conducted analysis of the structure and proper selection of materials for its construction, the adverse effect of vibrations may be reduced almost entirely.

In the construction of structures exposed to dynamic loads that cause vibrations, materials characterised by sufficient strength, fatigue durability, resistance to external factors (chemical, atmospheric) as well as homogeneity, i.e. identical physical properties throughout its mass are used. The material that meets all these requirements is undoubtedly reinforced concrete. Therefore, it is an essential and widely used construction material for dynamic load-bearing structures.

A typical example of reinforced concrete structures loaded dynamically in a deterministic manner and very often used in industry are foundations for machines. Therefore, in this paper, the most important issues related to their implementation, operation and maintenance was presented. In addition, a special attention was paid to the specific properties of materials used to build such structures.

1.2 The main tasks of foundations for machines during transferring dynamic loads

Foundations for machines are, in general, special building structures used to transfer loads from an operating machine to the subsoil. Foundations for machines subjected to industrial dynamic loads are engineering structures that require a slightly different approach in design than structures transferring only static loads. The purpose of these foundations is not just to transfer loads, but also to reduce vibrations occurring during operation of the machine, i.e. their damping and preventing redistribution to other elements of the building.

A properly designed foundation for machine should satisfy a number of conditions, which are as follows:

- to provide appropriate support for the machine,
- to satisfy the requirements of the supplier of the machine for its installation and use,
- to have adequate strength, durability and stability,
- to reduce transfer of vibrations to surroundings to an acceptable level.

It should be noted that foundations for machines (particularly foundations for hammers) are the most dynamically loaded building structures. They are subjected to dynamic loads, the magnitude of which varies in short intervals. For these reasons, they require precise static and dynamic calculations, accuracy in their implementation and care for them after they have been made.

The general rules of shaping and designing foundations for machines are described in several monographs, e.g. (Lipiński 1998, Bhatia 2011, Prakash and Puri 1988, Meyer 1998), chapters in monographs, e.g. (Kameswara Rao 2011) and publications, e.g. (Mehta 2013, Bhandari and Sengupta

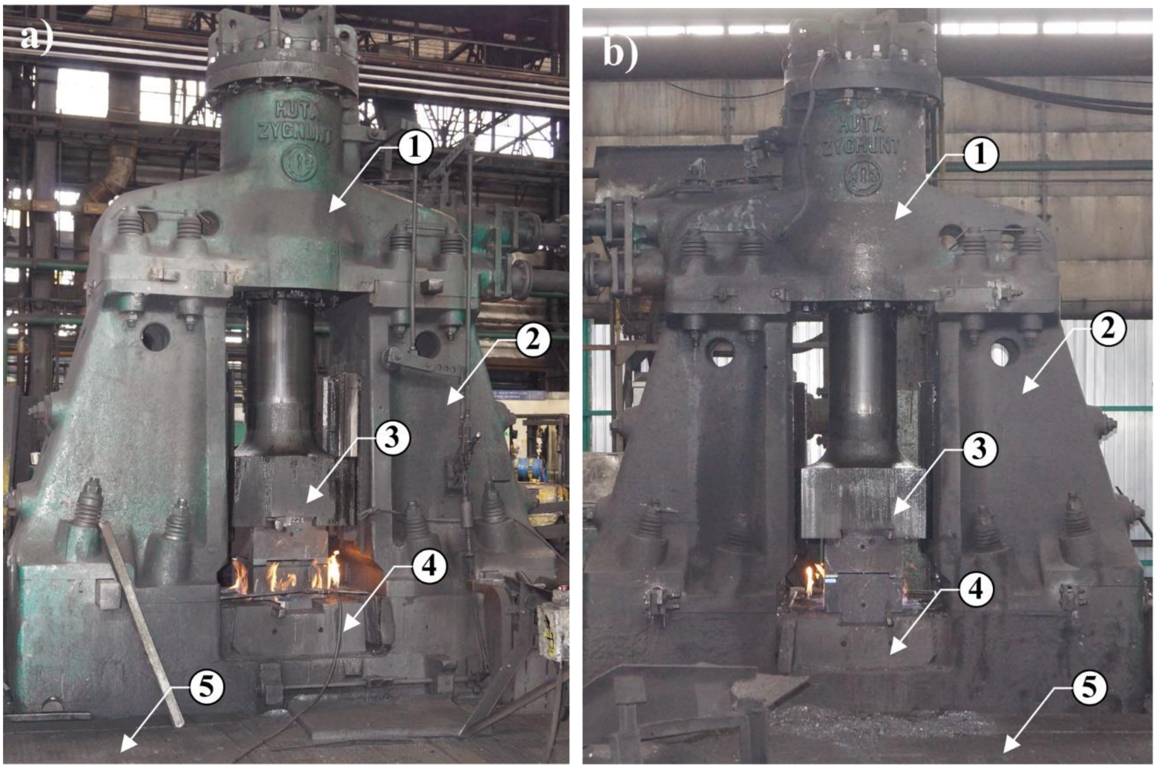

Fig. 2 View of two types of matrix hammers produced by ironworks Zygmunt (Poland): a) MPM 600, b) MPM 1000 B; 1– head hammer, 2 – body hammer, 3 – beater, 4 – hammer anvil, 5 – working platforms (photo by author)

2014, Prakash and Puri 2006).

However, the foundations for machines are a special type of construction that requires:

- technically and economically correct design,
- proper selection of materials for their construction,
- accuracy and precision in their implementation,
- appropriate maintenance during their operation.

The literature lacks specific guidelines for above problems. Therefore, they will be described in detail in this paper. The article presents the newest solutions both in terms of technology implementation foundations for machines as well as materials used in their construction.

2. Breakdown and structural systems of foundations for machines

2.1 Breakdown of foundations for machines depending on the machine type based on the foundation

For the design purposes of foundations for machine, it is basically needed to know loads generated during the operation of machine, which are transferred to the foundation, causing its movements.

Many types of machines generate dynamic loads so insignificant that they do not have significant impact on the foundation. For these machines, design of the foundation is virtually a static issue. Such machines are defined as quiet machines. The second group are the machines that generate significant dynamic loads, having a significant impact on the foundation. These are known as unquiet machines.

An exact breakdown on quiet and unquiet machines is often difficult to carry out. The assessment based on the observation of the machine during its operation is decisive. This particularly applies to machines with complex mechanical system. In further considerations, foundations for unquiet machines are subjected to a thorough analysis.

Depending on the type of machine located on the foundation, there are distinguished:

a) foundations for machines with impact action

Machines in those foundations act on them during work with a single impulse or series of impulses. It is one of the most important groups of machines because they generate the greatest forces during their work. Such machines include, among others, mechanical hammers and pile drivers.

Forging hammers belong to the group of equipment, which is characterised by high and even very high dynamism. The loads occurring during the operation of hammers are short impulses of considerable values generated by excitation forces. The main types of forging hammers are free forging hammers and matrix hammers. Fig. 2 shows pictures (during the operation) of two examples of matrix hammers.

It should be noted that, foundations for forging hammers are included in the building structures heavily loaded dynamically and require an individual approach. Some of the guidelines for the proper operation and maintenance of these structures are given in Section 5.

b) foundations for rotating machines

Dynamic impacts of machines in these foundations generate centrifugal forces of rotating parts. Such machines include: turbines, generators, fans, pumps.

c) foundations for machines with a crank system

The dynamic action of such machines is caused by the reciprocating motion of certain parts of the machine. Machines, which include: combustion engines, reciprocating machines, surface planing machines, most often cause harmonic variable forces.

d) foundations for machines of crusher type

The dynamic impact of such machines is caused by motions of breaking or crushing elements. Such machines include: breakers, crushing mill, stone crushers.

e) foundations for other machines

This group includes the foundations for machines such as rolling machines, machine tools for metal. The dynamic impact of such machines on the foundation can be different depending on the type of machine operation.

2.2 Main structural systems of foundations for machines

The structure of foundations for machines depends primarily on the dynamic character of work and dimensions of the machine.

If a quiet machine, performing slow or fast movements, is placed on the foundation, however, the mass of elements in motion is in relation to the total weight of the machine small, the foundation will have a simple structure and will be very similar to any other foundation for other building objects.

A more complex group are structural systems of foundations for unquiet machines. In order to systematise the methods of design and construction of engineering structures subjected to industrial dynamic loads, a conventional breakdown of foundations for such machines on three essential groups is introduced:

1) I group – block foundations,

The block foundations are the most commonly used type of foundation for unquiet machines. They are used for the following types of machines: reciprocating (both steam and combustion engines), compressors, electric motors, fans, pumps, mills, matrix and free forging hammers.

The block foundations are in the form of a massive body, of more or less regular shape. In such solid, there may be notches, indentations and openings for cables, the location of auxiliary equipment and the machine. The block foundations are constructed in the form of full block or adequately thick slab.

A certain variety of block foundations are the box foundations. They may have a form of an open box or closed, forming a monolithic closed box.

Depending on technological requirements, block foundations may have a high above-ground section, reaching even up to the level of the next floor of the building, or they may end up directly above the lowest floor level.

Generally, due to the structure and dimensions, i.e. width (*B*) and height (*H*), among block foundations, there are distinguished (Fig. 3):

a) foundation blocks:
- low foundation blocks, if $H/B \leq 1$,

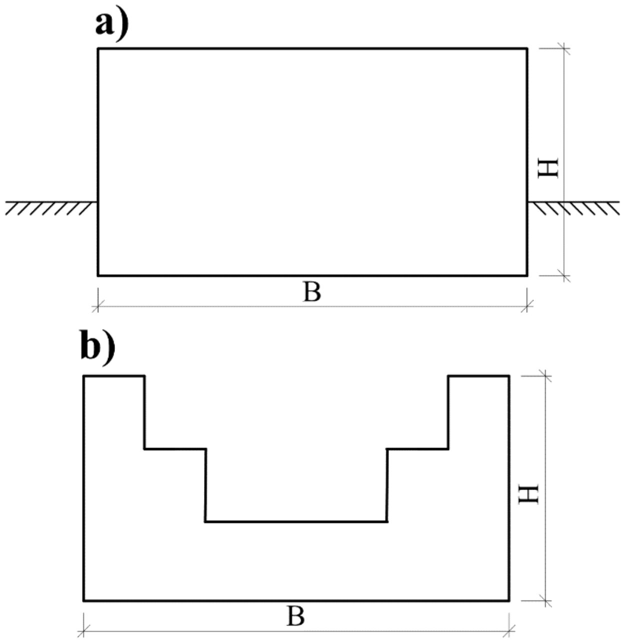

Fig. 3 Schemes of block foundations: a) foundation block, b) wall foundation

- high foundation blocks, if $H/B > 1$,

b) wall foundations (box).

2) II group – framework foundations,

Framework foundations consist of three structural elements, i.e.:
- bottom slab of large thickness, transferring the loads to the subsoil,
- columns fixed in the bottom slab, supporting a top slab,
- top slab – constituting a direct support for the machine – which is constructed as a system of intersecting transverse and longitudinal beams, usually in the form of grillage.

The spatial structure formed in this way is an arrangement of elements performing flexural-torsional vibrations under dynamic loads in contrast to the block foundation considered as a rigid solid vibrating on the elastic substrate. Such foundations are usually for high-speed machines, i.e. turbine sets.

In most cases, framework foundation is designed in such manner that the space between the bottom and top slab is used to carry out the installation or for media inlet and outlet. Often, other devices are located in this zone; necessary for the proper functioning of the machine or assisting in its work.

3) III group – support structures,

The support structures for machines are special structures that transfer static and dynamic loads, and which cannot be clearly classified into groups of block or framework foundations. The support structures for machines include:

a) ceilings loaded dynamically,
b) free-standing platforms loaded with machines,
c) support structures fixed to walls or columns of a building loaded with machines,
d) other structures lifting machines, and not having

the character of the block or framework foundations, for example reinforced concrete channels of circulating water, on which the pumps are set.

The scope and sequence of conducting dynamic calculations of support structures for machines depend primarily on:

- the type of analysed support structure,
- the dynamic character of the operation of machine.

It should be noted, however, that there are structures that combine characteristics of different types of structures such as box foundations, wall foundations or platforms loaded with machines, similar to framework systems.

In addition, due to the specificity of hammer operation, which generates dynamic loads in the form of impulses, in the group of block foundations, there is a breakdown: block foundations for non-impact machines and foundations for hammers.

In the next chapter, the main problems for design of all above groups of foundations for machines will be presented.

3. Problems with design of foundation for machines

Due to the specificity of work of foundations for machines, an attention should be paid to the following aspects. In particular cases, they may cause some difficulties in this type of structure. The most common problems in design of foundations for machines include (Lipinski 1998; Bhatia 2011; Prakash and Puri 1988; Meyer 1998):

a) thermal influences,

They are reflected in uneven, adversely affecting the machine, deformations of heated parts of foundations (particularly framework foundations) or the formation of additional forces acting on the foundation, when the body of the machine heats up significantly stronger than the foundation.

b) overturning forces acting on the foundation,

These forces can be: belt tensioning of the driving motor standing on a separate foundation or belt tensioning in belt conveyors as well as action of starting torque or moments of a short circuit. These forces are counteracted by a corresponding expansion of the foundation base.

c) monolithicity of the foundation structure,

It is obtained by the use of high-quality concrete, proper reinforcement of the structure and appropriate concreting technology (see Section 4), particularly, by avoiding breaks in concreting. The monolithicity of the structure is essential to provide the foundation with the established dynamic and static-strength systems.

d) corrosion of foundation,

It manifests itself in corrosion of anchor bolts and metal parts in the foundation as well as in corrosion of vibration isolation. The corrosion is prevented by carrying out appropriate maintenance works (see Section 5).

The chemicals, including technical oils, have also destructive influence on corrosion. These influences are prevented by the use of appropriate protective coatings (see Section 5).

e) influence of vibrations on the environment,

This influence should be reduced by locating the machines generating very strong vibrations away from sensitive objects or by the application of appropriate technical measures (vibration isolation) shutting off the source of vibrations.

f) determination of dynamic loads,

In the case of certain machines, the determination of exact values of dynamic loads transferred to the foundation causes significant difficulties. This is often due to lack of data regarding the moving masses or complex character of their movement as well as other factors. It is then necessary to apply analogies to other machines with known loads or the determination of loads based on measurements of vibrations of existing foundations with known technical parameters.

Considering the above problems a detailed recommendations for the implementation of foundations for machines were proposed. They include both requirements for the selection of construction materials with appropriate parameters as well as guidelines on the technology of construction these special constructions.

4. Conditions for implementation of foundations for machines

4.1 Characteristic of materials for construction of foundations for machines

a) general requirements for materials,

Requirements for materials used in construction of foundations for machines (which are loaded dynamically) are slightly different than the requirements to be met by materials of structures loaded statically.

There are four main requirements for such materials:

- adequate strength,
- high fatigue strength,
- homogeneity of material,
- resistance to chemical and atmospheric influences.

Below are the most important specific requirements and instructions on the application of concrete and reinforcing steel in foundations for machines.

b) specific requirements for concrete,

Generally, the minimum class of compressive strength of concrete required in the case of foundations for machines is C12/15. The exception are structures transferring impact loads from operating machines, i.e. foundations under hammers. In such cases, concrete class C16/20 – for smaller machines, C20/25 and C25/30 – for larger machines should be used.

To the group of small machines can include, for example electrical machines (engines, generator sets, compensators, etc.) or some machine tools (lathes, grinders, drills, etc.). Large machines include, among others turbine sets (turbo generators, turbo pumps, turbo blowers, etc.) or free forging hammers and drop forging hammers.

In foundations for machines, the required minimum concrete strength classes depend on the type of machine

Table 1 Concrete strength classes used in foundations for machines

Type of machines	Concrete strength class	
	Block foundations	Framework foundations
Machines with crank mechanisms (diesel engines, etc., crushers, mills, sieve screens, presses etc.):		
I, II and III dynamic category	C12/15	C16/20
IV dynamic category	C16/20	C20/25
Electrical and rotating machines (pumps, centrifuges, fans, generator sets):		
I, II and III dynamic category	C12/15	C16/20
IV dynamic category	C16/20	C20/25
Turbine sets with power:		
up to 20 MW	C16/20	C20/25
20÷100 MW	–	C20/25, C 25/30
> 100 MW	–	C25/30
Rolling equipment, machine tool	C12/15	C 16/20
Single energy impact hammer – *U*:		
U < 120 kJ	C20/25	C16/20
120 KJ ≤ *U* ≤ 400 KJ	C25/30	C16/20
U > 400 kJ	C25/30	C20/25

and its dynamic category (Lipinski 1998; Bhatia 2011). In the case of certain groups of machines, for example turbine sets and hammers, the choice of concrete strength class is influenced by the parameters of the machine itself, i.e. its power – in the case of turbine sets and energy of a single impact of the beater – in the case of hammers. The concrete strength classes used in foundations for machines are summarised in Table. 1.

When selecting concrete strength class, for foundations for machines, it should be taken into account that the lower the modulus of longitudinal elasticity, (i.e. the lower the strength class), the greater the fatigue strength is. Concrete of lower strength exhibits greater resistance to vibrations, which to a lesser degree reduces its compressive strength. In addition, high-strength concrete is characterised by increased brittleness when compared to ordinary concrete. For these two reasons, when selecting concrete parameters for structures loaded dynamically, never the main criterion is the high strength of material. However, it is important to always satisfy the minimum requirements (see Table 1).

Obtaining concrete with uniform characteristics throughout its mass is often more important than the high strength, as it is largely unused in reinforced concrete structures loaded dynamically and any subsequent damage to these structures is often a result of mistakes made during concrete mixing.

Therefore, despite the apparent ease of concreting of massive structures transferring vibrations such as foundation blocks, all possible measures to ensure high-quality concrete should always be applied. Concrete should be homogeneous, without surface imperfections indicating the presence of honeycombs or porous areas, shrinkage cracks, etc.

All discontinuities occurring in concrete structure may diminish the ability of a structure to damp vibrations. In addition, it should be remembered that if a structure, which in the future is to transfer dynamic loads, has some weak areas, i.e. seams caused by pauses in concreting, they will inevitably be the beginning of structure cracking.

Fig. 4 The view of aggregates from igneous rocks:
a) basalts, b) granites

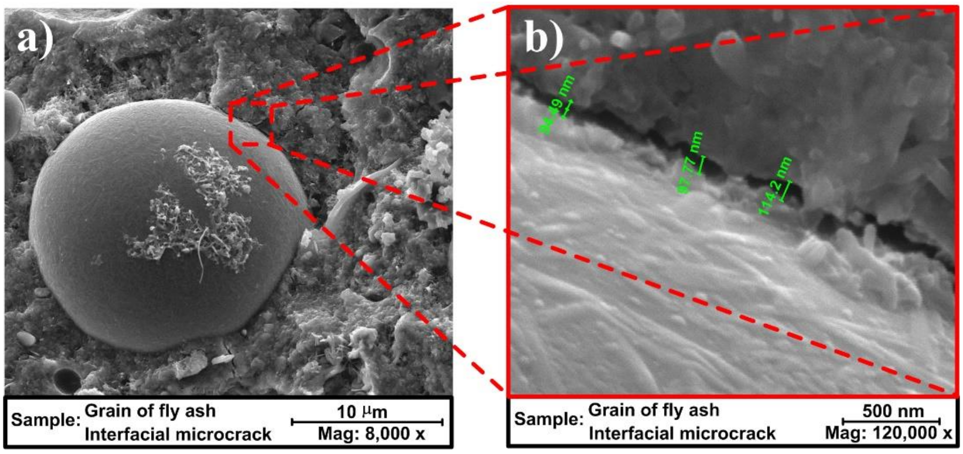

Fig. 5 An oval particle of fly ash with visible interfacial microcrack: a) Mag: 8,000 times, b) Mag: 120,000 times

Both laboratory and practical experiments prove that the destruction from vibrations originates in the already damaged areas prior to the application of load. Concentration of harmful stresses in weakened areas has the effect of decreasing both the material's durability and its resistance to aggressive surrounding environment. Microcracks and cracks occurring in the concrete also promote the corrosion of reinforcement (Hu *et al.* 2018, Lee *et al.* 2018, Savija 2018).

Furthermore, concrete of the foundations for machines should be of the highest possible quality. This requires the use of ingredients (for its construction) of proven high quality. Therefore, the composition of the concrete mix should always be designed by a professional technologist and verified with laboratory tests.

With regard to aggregates, it is required to use coarse aggregate – broken, originating from igneous rocks (Golewski and Sadowski 2006, Guodong *et al.* 2018). They can be aggregates from igneous plutonic rocks, e.g. granites or igneous volcanic rocks, e.g. basalts. The view of both types of aggregates is shown in Fig. 4. Moreover, aggregate grain size should be in optimal field, between the border grain size curves. It is unacceptable to use gravel sand and uncontrolled grain size.

In relation to the binder used, it is desirable to use slow-setting cements with low bonding temperature, optionally with chemical admixture retarding the setting of concrete mix, e.g. (Xie and Visintin 2018; Golaszewski 2012; Zhang and Li 2013). Due to the improved resistance to material cracking, it is beneficial to use binders with the addition of fly ash (up to 20%) in concrete subjected to dynamic loads after a long period of curing (Golewski and Sadowski 2017, Golewski 2017c 2018c, Owsiak and Grzmil 2015). However, there is a risk of cracking in concrete made on such binders at an early age, e.g. (Golewski and Sadowski 2012 2014 2016a, Golewski 2018b, Kosior-Kazberuk and Lelusz 2007). In addition, in order to ensure the tightness of the structure, concrete with a low water-binder (w/b) ratio should be used. A preferred value is w/b = 0.4 or lower, e.g. (Smarzewski 2019, Zhang *et al*. 2016).

Concrete with the addition of fly ash up to 20% is characterized by a favorable microstructure and very small microcracks in the Interfacial Transition Zone (ITZ) between the coarse aggregate and the cement paste. Small grains of fly ash from a few to several dozen micrometres are able to strengthen the weakest place in concrete, which is the ITZ (Bicer 2018). On the basis of the studies presented by Golewski (2018d) and Golewski (2019b), it was shown that mature concrete with the addition of 20% fly ash had significantly smaller crack widths in the ITZ between the coarse aggregate and the cement matrix than ordinary concrete. The beneficial results of earlier studies also result from the fact that fine fly ash particles form a compact structure in concrete.

In own studies it was also observed that the contacts of fly ash grains with a cement matrix have microcracks several times smaller than in the case of cracks between the coarse grains and the paste.

Fig. 5 shows at 2 different magnifications, the grain of fly ash visible in the structure of the concrete with the pozzolanic reaction products in the form of the C-S-H phase. The morphological forms of fly ash particle were analysing by means of a scanning electron microscope (SEM) FEI Quanta 250 FEG. In order to accurately measure the microcrack width, a very large magnification of 120,000 times was used. After thorough analysis, one can see that interfacial microcracks are very small and only about 100 nm. Therefore, it is almost 7.5 times less than the size of the microcracks at the ITZ between the coarse aggregate and the paste (Golewski 2018d, 2019b). The result is that the structure of such a composite is more homogenised and therefore more resistant to dynamic loads.

At this point it should be added that concretes with the addition of fly ash, which are not hazardous from the radiological point of view (Golewski 2015), are used successfully not only in the construction of foundation for machines but also in composite structures steel-concrete, e.g. (Zhang *et al.* 2016, Lacki *et al.* 2018, Yan *et al.* 2018).

c) specific requirements for reinforcing steel,

Reinforcement of foundation for machines loaded dynamically aims not only to transfer tensile stresses and moments caused by external loads, but also its task is to protect concrete against formation of shrinkage cracks. These cracks, harmless in structures loaded statically, in elements working under dynamic loads may increase at a rapid pace, changing the rigidity and inertia of the system:

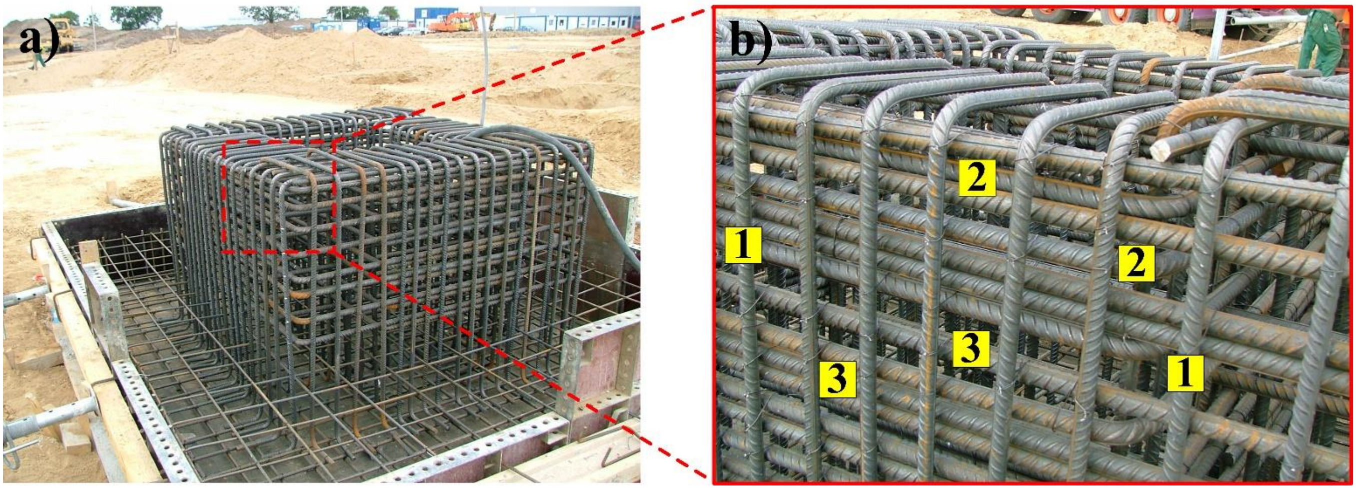

Fig. 6 A view of the reinforcement of the pocket foundation which will be loaded dynamically: a) side view, b) detail of the assembled reinforcement; 1, 2 - main vertical and horizontal reinforcement, 3 - structural reinforcement

structure – source of vibration.

Therefore, in structures loaded dynamically, the main reinforcement (transferring tensile stresses) from less brittle steel, i.e. lower classes, is preferred. It is sufficient to use reinforcing steel of regular C class, grade RB 300. It is permissible, of course, to use more brittle steel with higher yield strengths, i.e. RB 400 and RB 500. In such cases, however, an absolute verification of the serviceability limit state due to cracking is required - using only the exact method. Additionally, in order to avoid the occurrence of shrinkage cracks, a large amount of structural reinforcement, in which minor stresses form, is generally used.

Fig. 6 shows a view of the reinforcement of a pocket foundation which will be part of an industrial hall. The hall will be equipped with cranes and there will be dynamic loads. The magnification shown in Fig. 6b shows that in addition to the main reinforcement in the form of vertical frames, a very large amount of structural reinforcement is also visible. Its task is to protect the foundation against the occurrence of shrinkage cracks.

The minimum amount of reinforcement in foundation for machines loaded dynamically is determined according to the recommendations given for specific types of machines). In the absence of specific guidelines, general formulas given in EN 1992-1-1 (2004): Eurocode 2 can be used.

4.2 Comments on the construction of foundations for machines

When constructing foundations for the machine, the following specific rules should be observed:

- foundations should be concreted in accordance with specially designed program,
- concreting should be planned without breaks when concreting; it means that, it is required to construct foundations for machines from one batch – concreting from the beginning to the end without pauses.
- during concreting internal vibrators should be used, the diameter of the vibrator mace should be chosen so that it is possible to compact the mixture in every place without having to bend out the reinforcement,
- immediately after concreting, the surface of the foundation should be smoothed; it is important to obtain a horizontal, flat and smooth surface immediately after concreting of the foundation block as subsequent levelling or filling the surface with the cement mortar may be a source of damage,
- the accuracy of the foundation surface should correspond to the tolerance in the form of deviations from the levels in each direction, not more than 1.5 mm/m,
- if in the hall, where the foundation is concreted, the equipment causing strong vibrations is operating, it should be stopped for time of concreting and 24 hours after its completion,
- curing of concrete after concreting the foundation should be particularly careful, e.g. the niche for the anvil in foundations for hammers should be filled with warm water and all concrete surfaces should be maintained wet.

5. Guidelines regarding exploitation and conservation of foundations for machines

Similarly to a machine, which must be regularly conserved by fixing, cleaning and lubricating, foundation also requires a proper treatment. Any negligence in this field can cause foundation damage difficult to repair and consequently may lead to its destruction, e.g. (Xiaoquan *et al.* 2014). Below, in several groups, the most important guidelines regarding the proper inspection and maintenance of foundations for machines and vibration isolators are summarised.

a) general guidelines for the maintenance of foundations for machines

The works on the maintenance of foundations should be performed periodically when the machines are not working, e.g. when replacing the matrices in case of hammers. In order to verify the correctness of the foundation and to control the support of the machine on the foundation – during the first two months after the start-up of machines – inspections should be conducted once a week. Later, after gathering relevant experiences relating to work of the foundation, the period between inspections may be longer. The breaks between inspections should depend on the actual need, however, they should not exceed one month.

In the structure of machines, any changes are not allowed as this could increase the dynamic loads transferred to the foundation.

b) cleaning the inside of foundation

All residues after carried out technological processes, e.g. scale, sawdust and possibly other objects, which fell in the vicinity of the foundation should be removed.

With particular accuracy, all the cavities and openings in the foundation should be controlled, e.g. cavities for anvil head in the foundations for hammers.

Any objects and devices, which could slow down the freedom of movement of these foundations should not be in the area of block foundations and bottom slabs of framework foundations.

The correctness of the operation of system draining the bottom section of foundations should be checked. The accumulation of water in the area of foundations and flooding of parts of machinery should not be allowed to happen.

c) protection of the foundation against oiling

The locations of foundation, where the technical oils and lubricants may get – adversely affecting the concrete – should be protected with suitable covering, mortar or paint, e.g. with liquid glass. Sheet metal gutters or pipes carrying off oil out of the foundation, e.g. (Blaszczynski 2011a).

The locations where oil penetrates into the foundation block can be wells for anchor bolts. The protective pipes and the wells filled with cement mortar prevent penetration of oils and grease into the interior of the foundation, e.g. (Blaszczynski 2011b).

d) vibration-isolator control

In the foundation with vibration-isolators, their location should be controlled, and if the location changes, the vibration-isolators should be slid into the place.

The condition of springs and rubbers in rubber vibration-isolators should be very carefully checked. Any damages of vibration isolators should be removed immediately. If cracks in the springs have been observed, they should be replaced with the new ones with the same characteristics.

6. Summary

The purpose of this paper was to present the most important issues on the foundations for machines, which are structures loaded both statically and dynamically.

Based on the conducted analyzes, it can be concluded that, when designing and constructing foundations for machines, attention should be paid to such problems as:

- ensuring a perfect monolithism of the structure,
- protection of the structure against the phenomenon of a resonance,
- consideration at the selection of structural materials the adverse effect of their fatigue.

Taking these problems into consideration, it is recommended and even necessary at the design stage and for the execution of such structures:

- take into account the minimum recommendations regarding the strength of concrete (see Table 1),
- use materials for concrete production of the highest quality,
- use for prepare concrete mix broken aggregate from igneous rocks (see Fig. 3),
- use as a binder, cement modified with mineral additives and chemical admixtures, e.g. with 20% addition of fly ash,
- use a low w/b ratio,
- use a large amount of structural reinforcement,
- ensure the possibility of concreting the structure without pauses,
- vibrate the concrete mixture with internal vibrators with a suitable size of a vibrator mace,
- remember about careful curing of concrete after concreting the foundations,
- care for proper maintenance of foundations.

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