INSERTS FOR LIFTING AND HANDLING OF PRECAST ELEMENTS - WHERE ARE THE EUROPEAN CODES? A STATE OF THE ART

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Abstract: *Precast concrete elements are usually lifted and handled by means of lifting systems consisting of an insert embedded into the concrete and lifting equipment with a special connection device. These lifting anchors must be selected carefully and their design should be performed by experienced personnel based on rules which ensure safe solutions. However, up to now there exist no harmonized design rules or design models for inserts.*

The use of insert systems is controlled by the European Machinery Directive (MD). The MD, however, covers only steel failure modes and does not consider the behaviour of the anchorage material concrete which could yield concrete failures caused by the load on the inserts. On the other hand their load-bearing behaviour can be compared to headed studs for permanent use which are controlled by the European Construction Product Directive (CPD) and covered in detail by relevant codes. Due to technical gaps in the MD in some European countries national rules exist to design the inserts. Where no rules exist the manufacturers' design recommendations are applied.

This paper gives an overview on the complex situation with regard to the design of inserts and how this task could be resolved in the next future.

1. INTRODUCTION

The push over the last years to reduce construction duration has brought an increasing use of precast elements in concrete construction. These elements have to be safely moved in the precast plant as well as on the construction site. In most cases cast in inserts are used to lift and handle the precast elements. They have to meet an appropriate degree of reliability. Furthermore they have to sustain all actions and influences likely to occur during lifting and handling.

The qualification and design of inserts for lifting and handling of precast concrete elements, which are actually construction products, is not regulated in any European design standard referring to the European Construction Product Directive (CPD). These lifting devices have to comply with the European Machinery Directive 2006/42/EC [1] (MD) and therefore with the safety philosophy used in mechanical engineering. This means that in the case of lifting inserts the needs of the construction industry have to be satisfied by the theory and thoughts of the machinery industry given in the MD.

However, the MD only describes the design of inserts for lifting and handling with respect to the steel failure mode but does not provide any guidance on how to consider concrete as the material to be used for anchoring to avoid possible failure. Therefore in practice for the design National regulations are used or in the absence of such regulations the designers have to rely on recommendations by the manufacturers of lifting in inserts. These design approaches can show major differences between European countries and even similar types of inserts.

2. LIFTING INSERTS AND THEIR APPLICATIONS

In the precast industry in most cases lifting inserts as part of series-produced transport anchor systems are used. They consist of a cast-in-situ insert (lifting insert) permanently embedded in the precast element and the associated lifting accessory attached to it for a certain period during the lifting process (Fig. 1). In lifting condition, the lifting sling is connected to the lifting device. Lifting devices, accessories and inserts are usually proprietary systems developed and fine tuned to fit to each other by the manufacturer. This means that lifting devices and lifting inserts supplied by different providers or suppliers are usually not compatible with each other. The combination of different components may cause failure of the connection with unfavourable consequences to the precast element and the health of the personnel on site.

The repeated use of lifting anchors, such as for the relocation of crane weights, is only permitted in exceptional cases. However, multiple instances of slinging and lifting within the transport chain from the production of the precast part to its on-site installation are not considered a repeated use.

In order to ensure their safe and economical use, the application of lifting anchor systems (Fig. 2) is limited to certain defined fields of application. These include the lifting of walls, floors, pipes, bar-shaped and bulky elements. The specific fields of application have to be taken from the operating instructions provided by the manufacturers. In general, then the resistance values correspond to a minimum lifting concrete compressive strength of 15 N/mm²of the precast element at the first lifting operation.

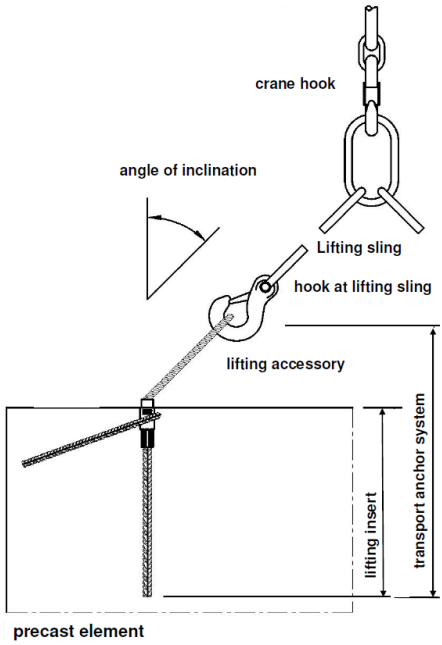

Fig. 1. Transport anchor system, definitions according to [2]

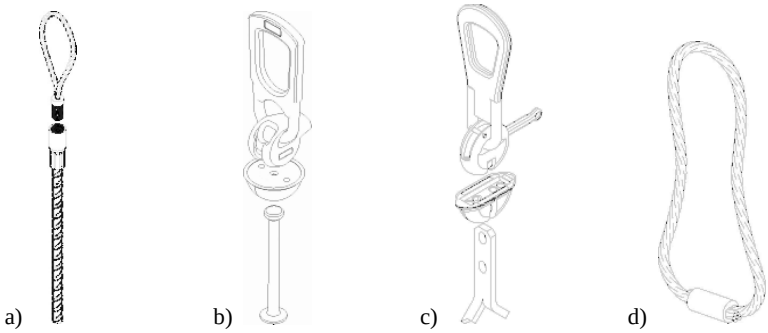

Fig. 2 Examples of transport anchor systems consisting of inserts and keys

3. REGULATIONS

3.1 General

The Machinery Directive (MD) serves to regulate machines and machine parts, as can be inferred from its name, to ensure free trade in Europe. It contains essential health and safety requirements relating to the design and construction of machinery and components.

If these requirements are fulfilled a product can be CE-marked. Then the manufacturer or supplier of the machinery confirms the compliance with the requirements of the MD and the marketed machinery represents a certain safety level in use.
The MD contains requirements on machines, machine parts and inserts made of steel that have to withstand actions during operation and lifting. This means that the directive has to be applied to lifting accessories. Therefore, these parts have to be CE-marked. However, the resistance of lifting inserts is not only influenced by steel failure. In addition to the properties of the material used for the lifting insert, its much more complex load-bearing behaviour is determined by the characteristics of the concrete used for anchoring purposes, the geometry of the precast element to be handled, i.e. its thickness and the position of the lifting anchors within the element and relative to its edges, as well as by additional reinforcement inserted and by the type and direction of the load acting on the lifting insert. These parameters have not been considered in the Machinery Directive. For this reason, CE marking is not possible solely on the basis of the Machinery Directive.
In addition, the Machinery Directive is based on essential health and safety requirements relating to the design of lifting inserts that differs significantly from the concepts actually used in structural codes. Therefore no “maximum load-bearing capacity” covering the entire range of applications specified can be stated for a lifting insert, as required by the Machinery Directive. In this regard, “maximum load-bearing capacity" should be interpreted to be equivalent to the notion of “permissible load” as commonly used in construction.
Obviously, lifting anchors are suffering from a gap existing between mechanical and structural engineering: The Machinery Directive mainly considers steel fracture as a mode of failure, is limited to a simple mass concept with regard to relevant actions, and uses global safety factors. By contrast, the construction industry considers the physical characteristics of all actions occurring while all possible failure modes must be verified, and the semi-probabilistic safety concept relies on partial safety factors for action and resistance.
Since the lifting inserts are used temporarily and not loaded permanently in the past and at present their qualification and design was and is not in the focus of structural Eurocodes.
In order to bridge this gap, there is an urgent need for the Machinery Directive to be amended by a supplement. However, no European mandate exists and therefore no European body has yet been working and on such an amendment. The regulations or status reports referred to in the following section can generally be used as a basis to create future regulations compliant with the Machinery Directive requirements whilst being harmonized across all EU member states.

3.2 CEN/TR 15728 “Design and Use of Inserts for Lifting and Handling”

About 15 years ago European precast producers had found that the catalogues published by various European and Asian lifting insert manufacturers made contradictory statements as to the resistance of comparable types of inserts. In addition, diverging opinions regarding the correct design also existed in the case of lifting aids manufactured by the precast plants themselves using reinforcement and prestressing steel off-cuts. For this reason, CEN TC 229 dealing with harmonized European standards governing precast concrete elements (construction products) under the CPD has prepared the status report CEN/TR 15728 on the “Design and Use of Inserts for Lifting and Handling” – with the objective to

create uniform regulations across Europe with regard to the qualification and design of lifting inserts. Since this field is under the responsibility of the Machinery Directive, to avoid conflicts information could be released not as a normative document but only in the format of a status report under the umbrella of the Construction Products Directive. CEN/TR 15728 was published in May 2008. Nor can CEN/TR 15728 be used as a paper to interpret the Machinery Directive as it explicitly excludes this purpose.

CEN/TR 15728 contains guidance on the design and labelling of lifting anchors, their selection in line with the intended application, assembly and insertion conditions, quantitative data to determine the actions on lifting anchors, e.g. in relation to formwork adhesion and dynamic loading resulting from crane lifting, methods to determine lifting anchor resistance through reproducible test results, and calculation methods. Excluding the calculation methods to determine lifting anchor resistance, which will be referred to in more detail in the following section, this status report is a major improvement for the use of lifting and handling of precast elements.

The characteristic resistance of lifting inserts in tension is calculated using equations and diagrams, amongst other means, that have been derived by a simple regression analysis on the basis of parameters stated in the catalogues of only a few manufacturers and products. However, in their catalogues, manufacturers include permissible loads for specific cases of application in the presence of custom-made or manufacturer-specific additional reinforcement. For this reason, characteristic resistance values were to be determined for the calculation methods included in CEN/TR 15728 where neither the failure mode of the lifting anchor for this specific use nor the material safety factor specified by the manufacturer were known. In addition, manufacturer-specific additional reinforcement was not considered accordingly. The calculation methods are not supported by physical background.

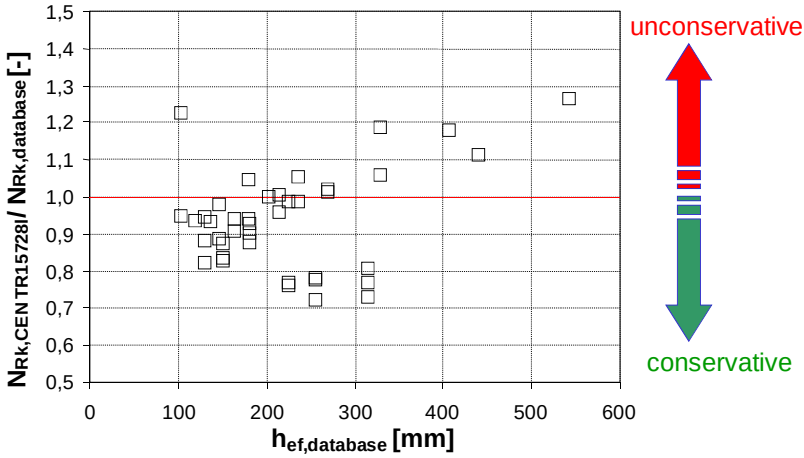

Fig. 3: Relation of resistance values calculated according to CEN TR 15728 to manufacturer specifications for expanding anchors in tension.

The input parameters required for the design equations according to CEN/TR 15728 must be taken from the catalogues or operation instructions for the inserts provided by the manufacturers, which, at the same time, state the resistance values recommended by the manufacturers. For the example of a lifting anchor system as shown in Fig. 2c), Fig. 3 demonstrates, that the comparison undertaken between the resistance value calculated according to CEN TR 15728 and the value provided by the manufacturer may lead to substantial misunderstandings and inappropriate use. The tensile strength determined according to the status report is almost 30% higher than the value guaranteed by the manufacturer in the case at hand. However, it should be assumed that a reputable manufacturer of lifting inserts knows very well, for product liability reasons at least, which resistance to failure his product has. This means that the design of lifting inserts according to CEN TR 15728 may result in unsafe values. It is thus recommended that lifting inserts be used that are offered by reliable and reputable manufacturers deriving their technical specifications from reproducible test results or in some cases by means of equations supported by physical characteristics. This prevents the application of "unsafe" calculated values in practice.

3.3 BGR 106: Safety rules for lifting inserts and lifting anchor systems used for precast concrete elements

In Germany, the use of series-produced lifting inserts is governed by the rules included in BGR 106 (previously "Safety rules for lifting anchor systems", ZH 1/17) issued by the Bau-Berufsgenossenschaft. They generally require that the actions on lifting inserts be determined whilst considering factors such as element weight, formwork adhesion during lifting, impact allowances, and the direction of force from the lifting sling. The rule does not specify any quantitative data regarding the magnitude of actions and safety factors to be applied that would be required for the design of the lifting inserts. The resistance of a lifting anchor can be determined either by calculation or by tests, where the lifting inserts are pulled out of the precast element, considering global safety factors for resistance. It remains unclear whether these safety factors should be used in relation to the mean value or the 5%fractile of a given resistance. In the case of the evaluation of test results, the resistance amounts to a maximum of 40% of the smallest concrete fracture value or 33% of the steel failure value determined on the basis of at least three tests. BGR 106 does not describe any testing conditions such as the geometry of the test rig or the loading rate, which can be used to significantly influence the test results.
The large room for interpretation left by BGR 106 results in a situation where the technical specifications for similar lifting inserts in identical applications provided by the manufacturers of lifting inserts inevitably vary to a considerable extent. Since the basic considerations included in BGR 106 rely on the state of the art of fastening technology as of 1986, a revision of this rule, or its replacement with a guideline based on the current state of the art, is urgently required.

3.4 VDI/BV-BS guideline 6205 "Lifting inserts and lifting anchor systems for precast concrete elements, basic principles – design – applications"

When it became apparent that the content of CEN TR 15728 would not achieve the intended objective of creating a regulation harmonized across the EU whilst considering the

Machine Directive requirements, in particular with regard to the design of lifting inserts, the Bundesverband-Bausysteme e.V. (BV-BS; a non-profit Association for Prefabricated Construction Systems) and the VDI Society for Civil Engineering jointly decided to prepare a uniform regulation for lifting inserts that would at least cover Germany. In 2008, a guideline committee was established in which designers and users, the precast industry, lifting anchor manufacturers, the Bau-Berufsgenossenschaft, testing institutions and research are equally represented. This committee aims to prepare a guideline that reflects the current state of the art and applies to all types of lifting inserts or lifting anchor systems, irrespective of whether they are series-produced or have been developed and manufactured for special applications. This VDI/BV-BS guideline 6205 is scheduled for completion in 2009.

The VDI/BV-BS guideline contains requirements and obligations imposed on the producers of lifting inserts and lifting anchor systems: It is reaching from the design criteria to the documentation of technical data to be included in the operation instructions. The guideline provides recommendations and explanations to designers and installers in the precast plant pertaining to the correct selection, design and use of lifting anchor systems during the processes of lifting precast reinforced concrete and prestressed normal concrete elements.

Fig. 4 shows the interactions of all parties involved. In addition, standardized lifting anchor testing and analysis methods are specified that can be used to come up with reproducible values as a basis to design anchors at a uniform level of safety. This guideline also considers the basic requirements of the European Machinery Directive but also includes the principles of the CPD and the practice in construction industry.

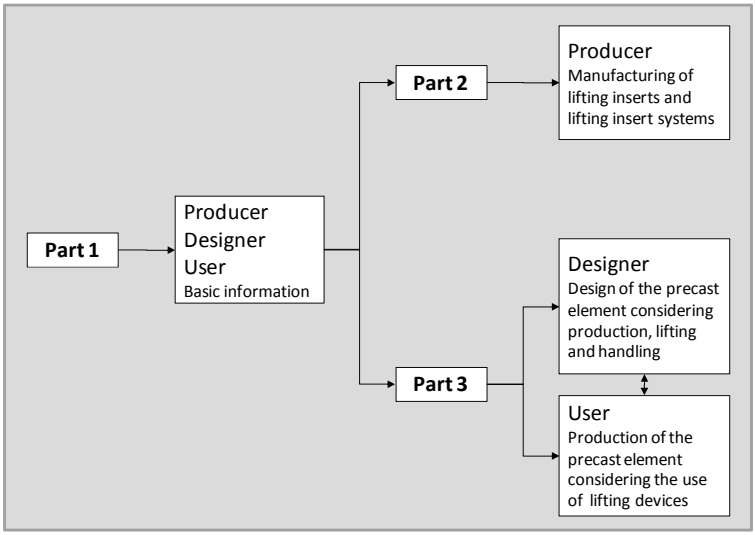

Fig. 4 Interactions between parts of the guideline, producers, designers and users of lifting inserts and lifting anchor systems according to VDI/BV-BS 6205 [5]

4. OUTLOOK

The CE marking of lifting inserts is required by the MD from December 2009. In consequence after December 2009 it is not permitted to trade lifting inserts without a CE mark within the EU. However, there is no European directive yet that could be used as a basis to issue the CE mark. A European committee to be commissioned with this work has not yet been established.
The VDI/BV-BS guideline 6205 could serve as a basis to discuss a European regulation supplementing the Machinery Directive since this guideline will represent the current state of the art after its publication in 2009, and can then be applied – at least in Germany – to ensure the uniform use of lifting inserts to a guaranteed safety standard.

5. SUMMARY

To date, no clear technical rules and regulations have been introduced to determine the conditions for the use of lifting inserts. The existing regulations leave too much room for interpretation, or may even lead to unsafe use in specific cases.
A future European directive or standard governing the design and use of lifting inserts that relies on reproducible results whilst clearly and unambiguously interpreting the Machinery Directive would be a major advancement for structural engineers, users in the precast plant, precast producers and producers of lifting anchor systems with a view to ensuring the safe lifting and handling of precast elements. Unfortunately, such a directive will not be adopted in the immediate future.
A first step in this direction will be the VDI/BV-BS guideline 6205, which is likely to be implemented in 2009 and reflects the current state of the art pertaining to the use of lifting inserts in precast concrete elements.

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