

REVIEW AND ANALYSIS OF REGULATIONS REDUCING MACHINERY SAFETY RISKS ON CONSTRUCTION SITES

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Abstract: This paper provides an overview of EU regulations related to machinery safety, with a particular focus on those frequently used in the construction industry. In addition, Croatian regulations governing occupational safety concerning dangerous machinery, in accordance with EU directives, are reviewed. Safety risks associated with the operation of standard construction machinery are identified, and examples of prescribed measures to mitigate these risks are highlighted.

Key words: EU Directive, Regulation (EU)2024/2847, Croatian regulations, construction machinery, risks, safety measures

INTRODUCTION

Numerous hazards are associated with the operation of machinery, representing potential sources of injury or health damage. In construction, machinery constitutes an almost indispensable component of work equipment, and serious injuries can result from several types of machinery. Studying safety risks is essential to determine measures that can either completely eliminate these risks or reduce them to an acceptable level. Many of these measures are mandated through various levels of legal regulation.

A machine's life cycle encompasses the phases of design, manufacturing, procurement, installation, use, maintenance, transfer, dismantling, modification, recycling/disposal, and sometimes also resale, rental, and lending. Therefore, to effectively reduce the risk of accidents through safety measures and the regulations that govern them, all phases and stakeholders involved in the life cycle of hazardous machinery must be considered. Many risks and costs associated with machinery-related accidents can be avoided through proper design, installation, and maintenance [1]. Regulations governing these aspects must be continually updated and improved in accordance with technological advancements and emerging knowledge of potential risks.

In Croatia, occupational safety regulations have been amended several times over the past 30 years, including those relating to the safe operation of machinery. As an EU member, Croatia is obligated to adopt all directives and regulations mandated by the Union. The new EU Machinery Regulation, which is scheduled to enter into force soon, requires a reassessment of high-risk machinery and the implementation of updated safety requirements [2]. This is particularly relevant for manufacturers, who will be required to design new machines with consideration for the risks associated with emerging technologies.

DEVELOPMENT OF EU REGULATIONS FOR THE SAFE OPERATION OF MACHINERY

In the EU, a machine is considered safe when it complies with all the technical and safety requirements specified in the relevant directives [1, 3]. Directives are legal acts based on Article 100 of the Treaty establishing the European Economic Community, requiring all member states to transpose them into their national legislation within a specified timeframe. The Framework Directive on Safety and Health at Work (Directive 89/391/EEC) and the first Machinery Directive (Directive 89/392/EEC) were both adopted in 1989. Directive 89/391/EEC is known as the social directive because it defines the minimum health and safety requirements that employers must ensure for their employees [3]. Directive 89/392/EEC introduced the obligation for machines to bear the "CE" marking, which must be clearly visible, legible, and

indelible. Manufacturers are required to carry out a conformity assessment procedure to affix the "CE" marking on a machine, which confirms that the machine meets the necessary health and safety requirements and, consequently, may be traded and used within the EU market [4]. In the last decade of the 20th century, several more machinery directives were adopted to complement and expand the scope of the first directive. The machinery directives address the design and manufacturing of machines and incorporate economic aspects by defining essential requirements and conditions for placing machines on the market. The current Directive 2006/42/EC, in force since the end of 2009, regulates the harmonisation of the essential health and safety requirements for machinery at the EU level [4]. It requires machinery manufacturers to identify all potential hazards and conduct a risk assessment addressing injuries and damage caused by machinery. Designers are required to eliminate hazards through safe machine construction or, where elimination is not feasible, to reduce risks to an acceptable level through appropriate measures [5, 6].

In addition to the Machinery Directive, machinery manufacturers must also comply with requirements set by the Pressure Equipment Directive 97/23/EC, the Electromagnetic Compatibility Directive 2004/108/EC, and the Low Voltage Directive 2006/95/EC.

Due to significant technological advancements over the past decade and an evaluation of the effectiveness of the current directive, which revealed certain shortcomings, the European Parliament and the Council published Regulation (EU) 2023/1230 in 2023, intended to replace it. The new Regulation revises the previous directive, although much of its content remains similar or identical. This Regulation has a 42-month transition period and will become fully applicable on January 20, 2027. However, several of its articles, including Article 6 – which allows for the amendment and supplementation of the list of dangerous machinery in Annex I – have already entered into force [2]. Unlike directives, EU regulations are directly applicable in their entirety across all Member States as soon as they enter into force, without the need for transposition into national legislation.

The main objectives of the Machinery Regulation are:

- To better address risks arising from digital and emerging technologies placed on the market, such as artificial intelligence, the Internet of Things, remotely controlled machines, collaborative robotics, etc.;
- To ensure IT security (secure connections between control systems and control networks);
- To check and update the current list of high-risk machines;
- To introduce new requirements for high-risk machinery, requiring enhanced assessment, monitoring, and control to ensure user safety;
- To eliminate interpretative ambiguities.

The Machinery Regulation defines a machine as "an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application [2]". A machine is also considered to be an assembly that, while missing only the components to connect it on site or to sources of energy and motion, as well as an assembly that is ready to be installed and able to function as it stands only if mounted on a means of transport, or installed in a building or a structure. Furthermore, a machine is defined as an assembly of linked parts or components, at least one of which moves, and is joined together, intended for lifting loads and whose only power source is directly applied human effort [2].

In addition to machines, the provisions of the new Regulation also apply to interchangeable equipment, such as that commonly used in construction machinery for lifting, load transfer, and earthmoving operations. The Regulation also covers removable mechanical transmission devices, safety components – including load and movement control devices, emergency stop systems, and restraint mechanisms for operators – along with software and digital components providing safety functions. Furthermore, lifting accessories such as chains, ropes, and webbing are included within its scope. For the application of this Regulation, the scope of application of the machine is an important factor, specifically that the machinery is intended for industrial use rather than for household purposes. Article 2 of the Regulation lists 23 types of products –

including equipment, machines, devices, and components – to which its provisions do not apply. Accordingly, the new Regulation, like the previous Directive, applies to the main construction machinery, such as various types of machines for earthmoving and concrete work, various types of cranes, and similar equipment. It is important to note that the Regulation applies only to machines placed on the EU market. Consequently, it applies to machines manufactured outside the EU but imported into the EU market, while it does not apply to machines manufactured within the EU that are intended for sale outside the EU.

Both the current Directive and the new Regulation require manufacturers to prepare appropriate technical documentation and to ensure that machines are accompanied by instructions for use and relevant information and warnings. Annex IV of the Regulation specifies the minimum content of the technical documentation. Crucially, the technical documentation must include risk assessment documentation. This report must include the procedures carried out during the design and manufacturing process, comprising a list of essential health and safety requirements applicable to the machine, a description of the protective measures implemented to meet those requirements, and a description of any residual risks associated with the machine, if present. Additionally, it should document the results of investigations and testing of components, fittings, or the machine itself, conducted by the manufacturer to ensure that the machine has been designed and constructed in such a way that allows it to be safely assembled and put into operation. The information and warnings on the machine should be presented using easily understandable symbols or pictograms, while any accompanying text should be clear and concise. Annex III. of the Regulation specifies the minimum content that instructions must include. Importantly, when machines are imported from other countries into the EU market, the responsibility for providing the instructions and technical documentation that accompany the machines lies with the importers [2].

The new Regulation explicitly allows instructions to be provided in a digital format [2], which offers benefits such as reduced costs associated with paper documentation and improved environmental sustainability. In relation to this, the Regulations set specific obligations for manufacturers when instructions are provided digitally, such as accessibility, the ability to print and download the instructions, and the duration of their availability [7].

Manufacturers generally carry out internal production control (self-certification) [7]. Figure 1 illustrates the sequence of internal production control procedures for machinery, in accordance with Annex VI of the Regulation.

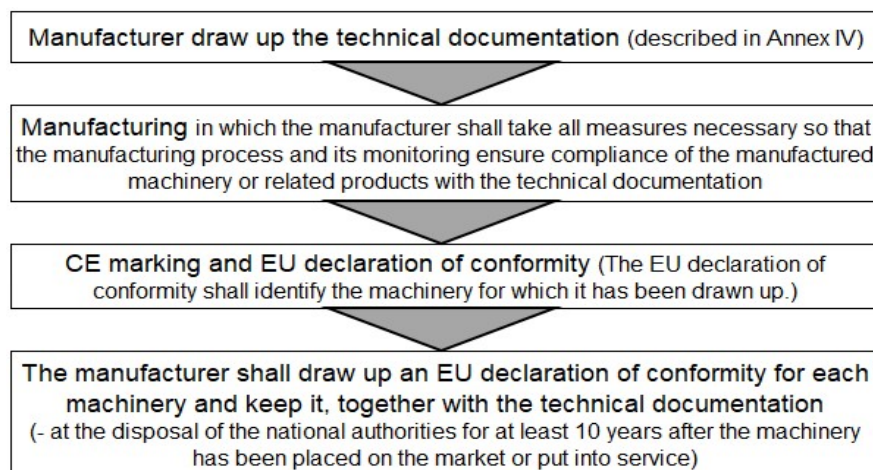


Fig. 1. Internal control procedures according to Regulation (EU)2023/1230

Annex I of the new Regulation contains a list of machines that present a higher level of risk and require a special conformity assessment procedure, i.e. certification involving a notified body. Of the machinery used in construction, this mostly concerns sawing and woodworking machinery and devices for the lifting of persons or of persons and goods (if involving a hazard of falling from a vertical height of more than 3 m). The list of machines in Annex I is divided into Part A and Part B. For machines listed in Part A, the conformity assessment must be

conducted by a notified body. Unlike the current Machinery Directive, manufacturers are no longer permitted to self-declare conformity, even if the relevant standards are fully met. Depending on the case, the second, the third, or the fourth conformity assessment procedure must be applied, as briefly outlined in Table 1. For machines listed in Part B of the list, two possible scenarios exist. If the manufacturer designs and constructs the machine in accordance with harmonised standards or common specifications specific to that category, covering all relevant health and safety requirements, the internal production control procedure may be applied. Otherwise, conformity assessment must be conducted by a notified body according to one of the three procedures applicable to Part A machines.

Table 1. Types of conformity assessment procedures provided for by EU regulation for manufacturers or importers of machinery

1) Internal control	2) EU type-examination	3) Full quality assurance	4) Conformity based on unit verification
It includes verifying compliance with the essential requirements for a given machine, a process most commonly undertaken by manufacturers or importers, as explained in more detail in Annexes VI and VIII of the Regulation.	For a machine to obtain the CE certificate, the manufacturer is required to carry out specialised testing through a notified body, as explained in more detail in Annex VII of the Regulation.	The procedure requires the manufacturer to obtain a certificate from a body authorized to assess the fundamental quality management system – covering design, production, final inspection, and testing of the machine – before commencing production, as explained in more detail in Annex IX of the Regulation.	This procedure applies to unique machines or related products that are not mass-produced. It is a novelty of the Regulation and is explained in Annex X.

Manufacturers of "smart", connected machines – those directly or indirectly linked to other devices or networks – must also comply with the requirements of Regulation (EU) 2024/2847 (Cyber Resilience Act), which entered into force at the end of last year. This regulation mandates that manufacturers and traders ensure cybersecurity of products with digital components throughout their entire life cycle, including maintenance. Automated and digital solutions on construction machines are increasingly relevant, especially when it comes to dangerous and demanding working conditions [8, 9], and the importance of these requirements in construction practices is expected to grow significantly in the near future.

ALIGNMENT OF CROATIAN LEGISLATION WITH EU REGULATIONS

The first Occupational Safety and Health Act in the Republic of Croatia was passed in 1996, and until the new regulations were passed, those from the Socialist Federal Republic of Yugoslavia were in force. Some of them are still valid, such as the Ordinance on Technical Norms for Cranes, which is important for the safety of machinery.

During Croatia's negotiations for EU accession, efforts were undertaken to harmonize national legislation with EU directives. The current applicable legislation in Croatia is the Occupational Health and Safety Act of 2014, which has been amended in 2014 and 2018. This Act, aligned with existing existing EU regulations, broadly governs occupational health and safety across all sectors. Additionally, a series of ordinances provides more detailed provisions and interpretations for specific areas within the Act. Based on Article 5 of the Act on Technical Requirements for Products and Conformity Assessment (2010), and Article 42, paragraph 2 of the Occupational Health and Safety Act, the Ordinance on Machine Safety and the Ordinance on the Inspection and Testing of Work Equipment were adopted following the entry into force of Directive 2006/42/EC. Directive 2006/42/EC requirements are implemented into Croatian legislation through the Ordinance on Machine Safety, which mandates the assessment of machinery conformity with relevant standards, health, and safety requirements for both placing machinery on the market and its use.

The Ordinance on the Inspection and Testing of Work Equipment regulates periodic inspections and testing but does not intend to compensate for possible non-compliance with the provisions of the Ordinance on the Safety of Machinery when placing them on the market and putting them into use. Its adoption led to the repeal of the previous Ordinance on the List of Machines and Devices with Increased Hazards (2002) and the Ordinance on the Testing of the Work Environment and Machines and Devices with Increased Hazards (2002 and 2003). Consequently, the term "machines and devices with increased hazards", previously listed in the repealed Ordinance, is no longer used in Croatian legislation [11]. However, it is important to note that the list of machines with increased hazards encompasses most machines commonly used on construction sites. The Ordinance on the Inspection and Testing of Work Equipment applies to work equipment that requires handling, control, or servicing by an equipment operator. For example, it does not apply to scaffolding and other equipment used for occasional work at height, which are inspected under separate regulations, nor to handheld mechanized or non-mechanized tools, or to work equipment that only requires start-up and shut-down actions for its intended operation. The scope of this Ordinance includes machines and devices, plants, and load-lifting and transport equipment; thus, standard construction machinery falls within its remit [11, 12].

Inspections and testing are conducted to verify compliance with health and safety requirements for work equipment, aiming to identify and rectify deficiencies that could endanger the safety and health of the operator or other personnel in the vicinity of the equipment's use [11]. An inspection refers to a visual assessment of the functionality of the work equipment, verifying compliance with health and safety requirements according to the manufacturer's technical documentation, confirming the availability of operating instructions, and assessing the maintenance condition of the equipment based on the manufacturer's guidelines or established occupational safety rules. Testing is defined as any other action necessary to determine individual, specific safety and health requirements, carried out using measuring and testing equipment [12]. Table 2 presents the intervals for inspections and testing that employers must ensure for the work equipment they utilize.

Table 2. Time of mandatory inspections & testing of work equipment according to Croatian regulations

- Daily visual inspection before using work equipment	
- Within the timeframes specified in the manufacturer's instructions for use and maintenance of the work equipment	- Before commencing use at a new workplace, if the work equipment has been relocated and subsequently disassembled and reassembled (e.g. tower cranes)
- Within the period determined by a special regulation	- In the event of exceptional circumstances that could threaten the safe operation of the work equipment, such as a change in the mode of operation, damage or defects to the equipment, or worker injuries related to the equipment
	- Following a decision by the labor inspector
	- Periodically, at intervals that must not exceed three years

Periodic safety checks of work equipment by authorized personnel do not compensate for non-observance of other prescribed measures. Rather, they serve as audits verifying the employer's fulfillment of obligations under the Occupational Safety and Health Act to ensure that work equipment and personal protective equipment in use are safe, well-maintained, fit for the intended work, and kept in good condition at all times [11, 13].

The Ordinance requires the preparation of a record of completed inspections and tests, and specifies the minimum information that the record must contain [12]. Documents of inspection and testing of work equipment issued in a Member State of the European Economic Area are recognized in Croatia for equipment temporarily used and not assembled at the workplace prior to use, provided these documents are translated into Croatian and written in Latin script, and the inspections and tests are conducted within the prescribed intervals [11].

The regulations emphasize that work equipment should be operated by trained workers, which indicates that training aimed at safe work is expected to lead to the correct use of appropriate personal protective equipment and compliance with the manufacturer's instructions for the equipment. This is expected to significantly reduce potential risks.

RISKS IN THE OPERATION OF CONSTRUCTION MACHINERY AND MEASURES FOR THEIR REDUCTION

Risk assessment increases the safety of machine operators and others potentially harmed by machine failure or unsafe operation. The ISO 12100 standard provides general guidelines for this process. The process of identifying hazards associated with machine operation and assessing the risks of those hazards is demanding for assigning the "CE" marking to the machine. As a first step, the Machinery Directive requires designers and manufacturers to identify hazards that may arise from the use of machinery. This is followed by determining and assessing the risk of accidents, based on the probability and severity of injury or health damage that may result from all foreseeable hazards during the machine's lifecycle, as understood at the time the machine is placed on the market [2, 5]. For machines placed on the EU market, residual risk should be reduced to at least an acceptable level through appropriate design and manufacturing. To achieve this, various safety components are used (such as those presented in Chapter 2), and manufacturers provide instructions for safe use. Annex III of the Regulation enumerates hazards that different machines may present, along with the corresponding measures manufacturers are obliged to implement to minimize these risks. Table 3 details the risks associated with operating the most common types of machinery on construction sites and the prescribed measures for their reduction.

Table 3. Safety risks when operating standard construction machinery (earthmoving, concrete, and lifting machines) and appropriate manufacturer measures for their reduction (according to [2])

Safety risks	Prescribed safety measures by machinery manufacturers
Risks of rupture during operation	The instructions for use shall specify the types and frequencies of inspections and maintenance operations required. Where applicable, they must also identify components subject to wear, along with the criteria for their replacement.
Risks related to moving parts of the machine	The machine's moving parts must be designed to prevent any risk of contact that could lead to accidents. If such risks are still present, appropriate guards or protective devices must be installed. Adjustment and maintenance points should be located outside hazardous zones, and tasks such as adjustment, maintenance, repair, cleaning, and servicing should be feasible when the machine is stationary.
Risks of slipping, tripping, or falling	Parts of the machinery intended for movement or standing by persons must be designed and constructed to prevent slipping, tripping, or falling. Where necessary, these parts should be equipped with appropriate handholds. Additionally, any residual risks must be clearly communicated through required warnings.
Risks due to machine movement	Visibility from the driver's (operator's) position must ensure that the machine and its tools can be operated completely safely under reasonably foreseeable conditions of use. Where direct visibility is inadequate, appropriate devices must be provided to eliminate associated risks. If possible, without increasing hazards, a cab should be installed at the driver's (operator's) position, which must include a designated place for the appropriate operating instructions. The movement of a self-propelled machine must only be possible when the driver/operator is at the control device. If there is a risk that operators or other persons being transported on the machine could be crushed between parts of the machine and its surroundings in the event of a rollover or tip-over, the machines must be equipped with a system that keeps persons in their seats or within the protective structure, while allowing necessary movements for work. A visual and audible signal must be provided at the driver's position to warn the driver when the seat belt is not in use. If there is a risk of overturning or tipping of self-propelled machines, or a risk of objects or materials falling onto the machines, they must be equipped with appropriate protective structures. If the machine is equipped with devices extending beyond its movement envelope (such as stabilizers or crane arms), the driver or operator must be able to easily verify before movement that these devices are safely positioned. Mobile machines of greater height (e.g. cranes) must be designed and equipped to prevent the risk of possible contact with overhead power lines or other objects.
Risks associated with lifting machinery	To avoid potential collisions with persons, equipment, or other machines, the control position on the machine must be positioned to provide the broadest possible visibility of the paths of moving parts. Machines must be designed to eliminate the risk of loads falling from their carriers. Machinery with a max. working load ≥ 1 t or a maximum overturning moment $\geq 40,000$ Nm must be equipped with devices to warn the operator and prevent hazardous movements in the event of overloading or exceeding the overturning moment.

	Lifting accessories and their components must have a specified number of permitted uses, and each individual part of a chain, rope, or webbing sling that is not part of an assembly must be marked with its maximum load capacity. The working coefficient (safety factor) of lifting chains must comply with the appropriate safety level, typically with a value of 4.
Risks related to pedestrian-controlled moving machinery	The movement of pedestrian-controlled self-propelled machinery shall only be possible if the operator is continuously engaging the appropriate control device.
Risk of vibrations	Machines must be designed to minimize risks arising from the vibrations they generate, reducing these to the lowest possible level (e.g. the seat must be designed in such a way that vibrations transmitted to the operator are reduced to the lowest possible level), preferably at the source of the risk.
Risk of noise	Machines must be designed to ensure that risks arising from airborne noise emissions are reduced to the lowest possible level, preferably by addressing the source of the noise.
Risk of lightning strike	Machines requiring protection from the lightning effects during operation must be equipped with a system designed to safely conduct the resulting electrical charge to the ground.
Risk of static electricity	Machines must be designed to prevent or limit the accumulation of potentially hazardous electrostatic charges and, where necessary, be equipped with a system for safe discharge of such charges.
Risk of fire	Machines must be designed to eliminate any risk of fire or overheating. In addition, they should incorporate designated locations for the installation of fire extinguishers or be equipped with built-in fire suppression systems.

Regulation (EU) 2023/1230 stipulates that, under the intended conditions of machine use, discomfort, fatigue, and the physical and mental limitations of the operator must be eliminated or reduced to a minimum, considering ergonomic principles. This includes avoiding demanding working postures or movements and manual efforts that exceed the operator's capacity [7]. The elimination or reduction of risk must be the first solution, meaning that technological and organizational measures take priority over measures related to workers' behavior [6]. Employers (construction contractors) are not required to duplicate the risk assessment conducted by the manufacturer in accordance with the Directive. Still, they must identify the residual risk associated with using the machines they operate. Even when machines comply with EU regulations, it is usually necessary to define and implement appropriate measures to reduce any remaining hazards. Residual risk mitigation involves not only timely inspection and proper maintenance of work equipment, but also effective planning and coordination of occupational safety measures at the construction site, effective communication and instruction of workers, worker training, and the use of necessary personal protective equipment [6].

CONCLUSION

With the advancement of technology and the evolving understanding of safety risks, regulations concerning the safe operation of machinery are continuously developing. The transition to the new regulatory framework presents challenges for stakeholders throughout the machine lifecycle, requiring adaptation of practices and ensuring compliance with updated requirements. To facilitate implementation and maintain high safety standards, the literature emphasizes the importance of adequate training and effective communication [14].

The new EU Regulation is primarily important for machine manufacturers, as the reduction of injury and damage risks is achieved mainly through the production of safe machinery that incorporates ergonomic principles and appropriate safety components, etc. However, the regulations also impose obligations on employers (construction contractors) to provide safe working conditions for their employees. Therefore, they must ensure the use of machinery that complies with all prescribed requirements. Consequently, companies involved in construction must consider the new Machinery Regulation during risk assessments for all machines purchased or significantly modified after January 20, 2027. Familiarity with the new regulations on the safe operation of machinery is also important for all professionals involved in planning work processes and workplaces, including those responsible for the detailed construction project execution plan, machine installation and maintenance personnel, and occupational

safety coordinators who oversee and coordinate safety measures on construction sites with multiple contractors.

Even when operating machinery that complies with all safety requirements, residual risk must be reduced to an acceptable level through regular inspections and condition testing of the machinery, combined with adherence to occupational safety regulations.

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