MEKA PRO THE CABLE MANAGEMENT HANDBOOK

ESSENTIAL PARTS OF USEFUL
STANDARDS AND REGULATIONS,
AND ADDITIONAL PRINCIPLES BEHIND
THE CABLE MANAGEMENT SYSTEMS

MEKA®

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INTRODUCTION

Meka Pro manufactures high-quality cable management systems in accordance with many standards, regulations, and instructions. The aim of this book is to present essential parts of useful standards and regulations, and additional principles behind the cable management systems to support all stakeholders (developer, designer, contractor, construction worker, inspector, and maintenance persons) in their daily work with the cable management systems. Together with Meka Pro's catalogue, installation instructions, fire-resistant cable support system -brochure, and YouTube -channel this book composes a comprehensive source of information on the cable management systems.

This book covers cable ladder systems, cable tray systems, and associated system components. This book does not apply to any current-carrying part and cable ladder systems are strictly forbidden to use as a ladder or walkway for people. Cable management systems are designed for use as supports for cables and not as enclosures giving full mechanical protection.

This book is a collection of items of general information related to the subject of cable management systems. It is not intended to be used as an authority for design, construction, or use of cable management systems. The design, construction, and use of the cable management systems shall only be undertaken by skilled workers familiar with electrical and mechanical installations in light of currently accepted construction, design, and engineering practices together with local legislation and regulations. Skilled workers ensure safe working too.

While great care has been employed to ensure that the tables, figures, and formulas contained herein are free of errors, absolutely no warranties, either expressed or implied, are made as to the accuracy or completeness of any such tables and formulas contained herein. Neither Meka Pro nor anyone else who has been involved in the preparing, producing, or delivering of this publication shall be liable for any direct, indirect, consequential, or incidental damages arising out of the use, the results of the use, or inability to use such publication, even if Meka Pro has been advised of the possibility of such damages or claim.

CHOICE OF CABLE MANAGEMENT SYSTEM

Several stakeholders are participating in the choice of the cable management system, either directly or indirectly. Designers, developers, operators, contractors, construction workers, and inspectors are looking at the cable management system from their perspectives. They all are considering factors like safety, construction object, environment, life cycle, load capacity, fire resistance, expandability, and cost efficiency from their own ends.

As shown, many stakeholders and at least as many variables are involved in the choice of the cable management system. Therefore, detailed, internationally comprehensive instructions on the choice of the cable management system can't be given in one manual. Each factor, such as environment and expandability, could have a separate theory book, and each stakeholder, e.g. operator and inspector, has their own country-specific rules and legislations to know and understand. Though this manual can't give comprehensive and legal instructions for the choice of the cable management system all over the world, some condensed background information can be provided to support selectors in their work.

In any situation, local rules and legislation shall be complied with. The cable management system shall be designed and manufactured in accordance with local or international standards and assembled according to standards and installation instructions. For example, Meka Pro designs, manufactures, tests, and certifies its products in accordance with the standard IEC 61537, which covers widely the cable management systems. Standard IEC 61537 is harmonized under the Low voltage Directive 2014/35/EU (LVD) so that cable management systems have the conformity assessment process.

Corrosion resistance, and hence environmental suitability and lifetime of Meka Pro's products is categorized in accordance with the standards ISO 12944 and ISO 10289 in addition to the standard IEC 61537. Meka Pro's products are made of materials and material coatings (surface finishes) declared in standards EN 10130, EN 10131, EN ISO 4042, EN ISO 2081, EN 10346, EN ISO 1461, EN 10088, EN 10169, ASTM A240, and ASME SA240. As shown, Meka Pro designs and manufactures versatile products in accordance with an extensive list of standards.

All the above-mentioned standards create an extensive base for the **safety** of cable management systems that should always be the first considered topic in every stakeholder's agenda and priorities when choosing the cable management system. Above mentioned standards often set unambiguous limits and instructions to many factors of the cable management systems, e.g. they define the minimum strength of used materials, and give instructions to define corrosion resistance, etc. Part of the safety is that products are marked and identified according to standards. Obviously these standards also provide instructions to ensure the fire resistance of the cable management system.

The above-mentioned standards support suitable cable management systems choice for different **construction objects**. Residential buildings have different requirements than factories. For example, the environmental and climate conditions may be different as well as the aesthetic requirements from the operator. The given standards define the corrosion resistance of the components so that each specific construction can receive a suitable cable management system. There are also essential standards related to different materials or surface finishes so that the selector can choose an appropriate appearance. Naturally, the given standards support the choice of the cable management system with optimal strength for either industrial, commercial or residential construction.

Loading is an essential factor in the choice of a cable management system. A too heavy load will break the cable management system immediately and even a less substantial overload will shorten the life cycle of the cable management system. The above-mentioned standards carefully describe the definition of the **safe working load (SWL)** of the cable management system and give instructions on how to define the safe working load of the cable management system. It is then possible to choose a suitable cable management system, which is cost-effective, safe, and potentially has extra capacity for future extensions. The given list of standards also includes material standards, which define the minimum strength requirement of the materials used and their impact on the loading of the cable management system.

The environment and expected lifetime of the cable management system are closely related to the construction and loading, topics presented above, and so included in given standards. Construction is defined by the environment. The cable management system in rural environment does not need similar corrosion protection to that installed on an oil rig. Likewise, if the corrosion protection of the cable management system on an oil rig has been chosen according to a rural environment, its lifetime will be short. The environment is covered in the same standards as corrosion resistance. In addition to corrosion, the load on the cable management system has a strong impact on the cable management system's lifetime as shown in the previous chapter. The above-mentioned standards give clear instructions on how to define the safe working load of cable management systems. Therefore, if the cable management system is designed in accordance with the given standards, selectors can determine the correct cable management system and control its lifetime, providing they know the environment and planned load on the system. Suitable load, together with right corrosion protection should provide a long and optimal life for the cable management system.

The above-listed standards enable the **expandability** of the cable management systems in the future. The listed standards require manufacturers to create proper product documentation and store it. Therefore, it is still possible to procure products according to obsolete designs in future years. Overall, proper documentation makes it possible to compare new systems with existing systems and hence make reliable extensions to existing systems without purchasing an entirely new system. This protects the environment and enables more cost-efficient repairs.

The given list of standards creates the base of **cost-efficiency.** Though standards and standardized processes may cause some extra costs, the transparent and standardized operations at every level increase the efficiency of the total chain, from design through to recycling. Designers have clearer initial information, sourcing understands the required properties of suitable materials, inspectors immediately know the basics of the system, etc.

At the moment international standards on the **fire safety** and fire resistance of cable management systems do not exist, only local and regional standards are valid. The lack of clear standards cause confusion and provides the possibility to publish various fire certificates for cable management systems. Despite the missing standards, good and recommended practice is to test the cable management system in accordance with the standard EN 1363-1 and incorporate cables into the test set-up. The concerned standard defines the temperature and pressure of the fire test. It is then possible to declare comparable fire resistance test results in accordance with the expected functionality of the system. Sometimes the cable management system collapses when exposed to fire, sometimes the electrical functionality stops due to heat. As the failure method cannot be forecasted reliably, the system should be tested in accordance with the standard, so that the selector can purchase a reliable and safe cable management system fitting each specific construction.

Sustainability is an essential topic in all industries nowadays, including cable management system manufacturing. It means meeting the needs of the present without compromising the ability of future generations to meet theirs. In sustainable operations, environmental, social, and economic considerations are balanced holistically to ensure long-term well-being for people and the planet. Operating sustainably also strengthens a company's ability to manage risks, comply with legislation, build trust with stakeholders, and attract talented employees. **Environmental sustainability** focuses on protecting natural ecosystems, conserving resources, and reducing pollution. It includes actions such as minimizing carbon footprints and promoting renewable energy. **Social sustainability** emphasizes equity, human rights, and community well-being. Key elements include safe working conditions and employee satisfaction. **Economic sustainability** supports long-term growth and ethical practices without harming social or environmental health. It involves responsible financial management and investments that preserve natural and human capital.

As shown in the above chapters, many factors must be considered when choosing the cable management systems: safety, construction object, environment, lifetime, loading, fire resistance, expandability, and cost-effectiveness. As many specialists, such as designers, developers, operators, contractors, construction workers, and inspectors, influence the choice of cable management system, it is challenging to give an all-inclusive response and recommendations in a short, simplified way. Hopefully, this short chapter encourages the reader to continue to the next chapters that provide more information in the broad field of cable management systems. In any case, do not hesitate to contact Meka Pro for further support and information on the choice of the optimal cable management system for your specific needs.

CABLE MANAGEMENT SYSTEM DESIGN TOOLS AND BUILDING INFORMATION MODELING

Building Information Modeling was presented and described for the first time as early as 1962. The term "BIM" was first used back in the '90s. Nowadays, BIM is mandatory in many building projects, and it is understood as both a process and 3D modeling software. The use of BIM is continuous throughout the building life cycle.

Building information modeling, or building information management, is a process, which is based on models used during the building's or infrastructure's life cycle. The process is collaborative, which allows multiple stakeholders to work within one model simultaneously during the building's life cycle. Information can be updated continuously, and updates applied automatically to all models. Therefore stakeholders, designers, architects, owners, maintenance, etc. can make decisions based upon accurate and up-to-date information at any given time.

Building information models provide more functionality and benefits than traditional 2D or 3D CAD models, though they also visualize the model parametrically. Building information models are intelligent objects as if digital twins to the real buildings or infrastructures. Different factors and their impact can be reviewed and tested in a digital environment before they are executed in real life. If changes are then implemented, all models and related objects update accordingly. This is a notable benefit in building maintenance, and especially in the design phase when many stakeholders are working on the same project.

The data or information included in the building information model is not carved in stone, but the data is adjustable and can be modified as required. The data may contain e.g. materials, dimensions, costs, geographic information, schedules, risk analysis, etc.

Autodesk Revit is one of the software applications built for BIM. Revit itself is not BIM. Revit creates objects, which include data that stakeholders can see in different views, both 2D and 3D. Objects may be related to each other, so if one object is modified related objects change also, and of course in all views and lists.

Meka Pro offers all engineers a free Meka Revit Plug-in software extension for Autodesk Revit. This plug-in automates and simplifies the design workflow, enabling users to generate accurate parts lists and detailed images directly from the model. It enhances project precision and efficiency. The extension plug-in includes Meka Pro's extensive product range and pre-validated configurations.

Meka Pro's industrial solutions are available also in Aveva's product library.

INSTALLATION, PLANNING AND EXECUTION / CONTRACTOR AND CONSTRUCTION WORKER

Meka Installation Instructions -manual is recommended to follow for proper and safe installation of Meka Pro's products. Meka Installation Instructions -manual presents detailed installation instructions for joints, supports and coverings in cable ladders, cable trays, wire mesh trays and lighting support rails. Meka Pro's YouTube -channel has installation videos to demonstrate installations and assembly examples are presented in Meka Pro's catalogue.

Cable management systems shall always be installed by skilled workers to ensure safe and proper installations according to standards, local rules, and regulations. All installation personnel shall wear suitable safety equipment and clothes to ensure safety, e.g. safety gloves are recommended to avoid cuts. (See: Figure 1) In addition to safety equipment, proper tools shall also be used during installation to secure safe assembly and an undamaged system, e.g. impact wrenches or other impact tools shall not be used for tightening bolts. (See: Figure 2) Although the systems would likely support human weight, cable ladders and cable tray systems are not intended to be used as support at any point during installation. (See: Figure 3) Cable ladder and tray systems are also not intended for use as current-carrying parts. (See: Figure 4)

FIGURE 1
Safety gloves and other safety equipment shall be worn during installation to avoid injuries.

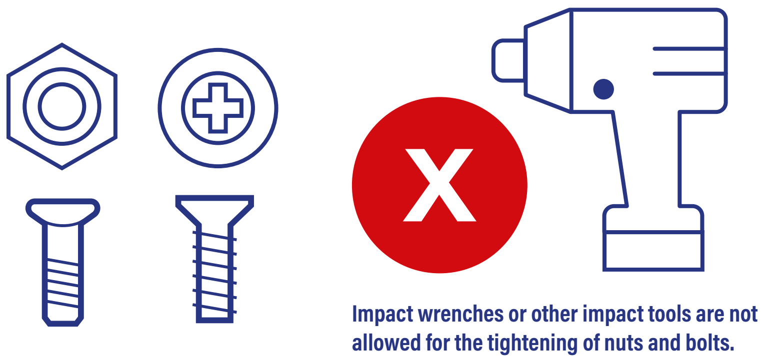


FIGURE 2
Cable management system's bolts and nuts shall not be tightened by impact tools.

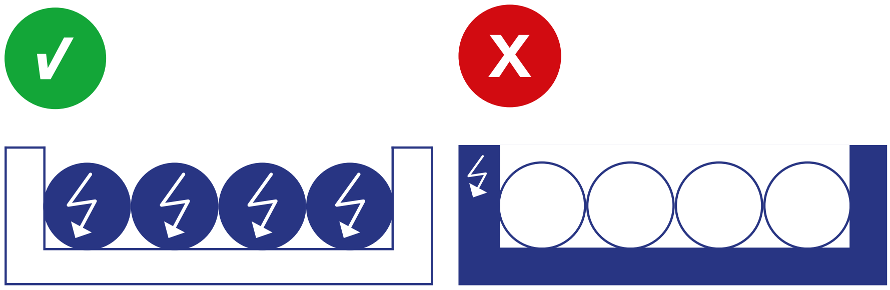


FIGURE 3
Walking on cable ladders is strictly forbidden.

FIGURE 4
Cable ladders and trays shall not be used as a current-carrying part.

LOADING AND DEFLECTION

Cable management systems must never be allowed to be overloaded. Each component has a defined safe working load (SWL), which is not allowed to be exceeded. The SWL is given in the catalog or datasheet as a number or diagram. (See: Figure 5) As shown in Figure 5, the span (L) has a clear impact on the SWL, a shorter span enables a larger load and vice versa.

Cable management systems are intended to carry static loads only and dynamic loads are not allowed. (See: Figure 6) Dynamic loads will cause fatigue stresses, which are much more destructive than static loads. A rough rule of thumb is that the SWL for a dynamic load is approx. 30-40% of the static load's SWL. In addition to a smaller SWL, a dynamic load may cause the loosening of screw joints, in which case extension pieces (such as SSU) may separate. If the cable management system is required to operate under dynamic loads, the suitability should be checked with the manufacturer or a responsible vendor and may require additional testing and certification.

Standard IEC 61537 declares that the practical mid-span deflection of each cable ladder span shall not exceed 1/100th of the span, i.e. a three-meter span could deflect by only 3 cm. (See: Figure 7) Cable trays are recommended to be installed so that the mid-span deflection of the tray does not exceed 1/200th of the span on the visible section.

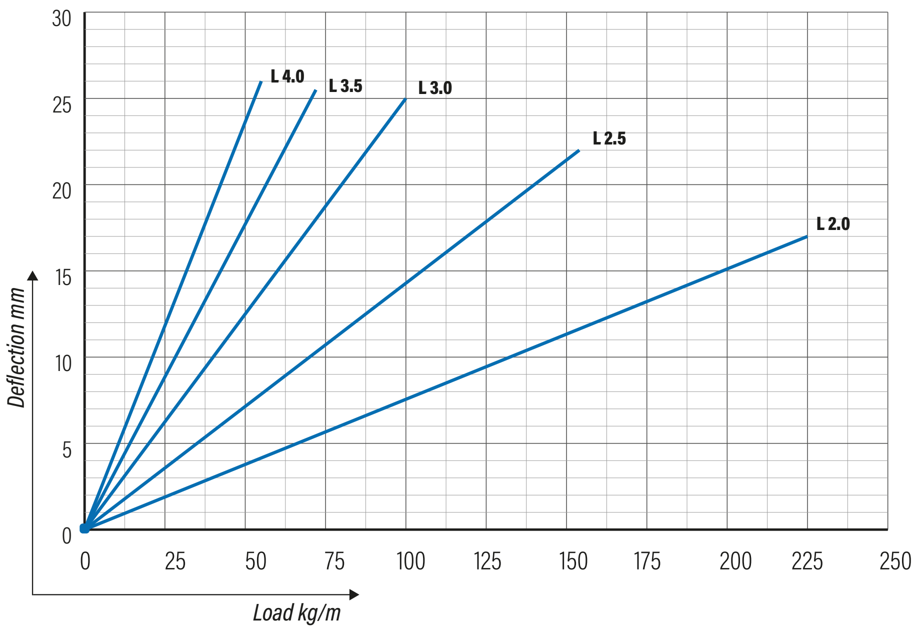


FIGURE 5
Safe working load (SWL) and a corresponding deflection of the cable ladder. Though the SWL is 1.7 times smaller than the destructive load, SWL shall be exceeded under no circumstances. For example, acc. to presented diagram, the load should be 225 kg/m or less, if the span (L) is 2 m. In that case, the deflection would be 17 mm or less in the middle of span. Corresponding values for a 3-meter span (L) are 100 kg/m and 25 mm.

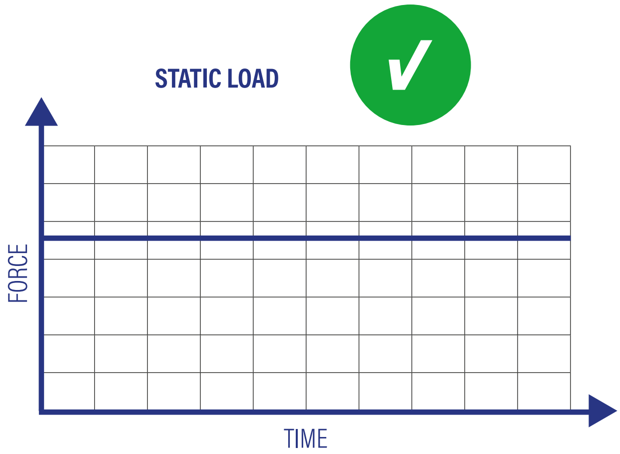


FIGURE 6

Cable management system shall not be under dynamic loading.

Whether following the standard's requirement or a customer's stricter specification, the deflection must be considered when the cable management systems are designed and installed.

The locations of the supports and joints have a strong impact on total deflection and load of the cable ladder or tray. Therefore, the manufacturer or a responsible vendor must provide the maximum deflection and load related to the particular location of the joint. The maximum deflection or load alone, does not provide enough information on the cable management system's strength. Meka Pro provides deflection and load of the cable management system when the location of the joint is 1/5th – 1/4th of the span from the support. (See: L/5 in Figure 8) If the joint is in the middle of the span, the declared values do not agree with the system, the deflection and the allowed load may be different. It is also worth noting that joints are not allowed to be located precisely above or below the support.

The single-span system (jointless system) carries a smaller load than the coupled system. (See: Figure 9) If the single span's maximum load is not given by the manufacturer or a responsible vendor, the exact load capacity of the single-span system shall be checked with the manufacturer or a responsible vendor, though 50% of a multi-span (jointed/coupled) system's capacity is considered to be a safe rule of thumb.

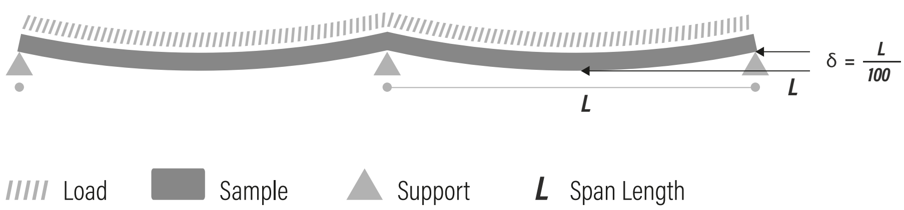


FIGURE 7

The maximum allowed deflection of the cable ladder or cable tray is limited in accordance with span.

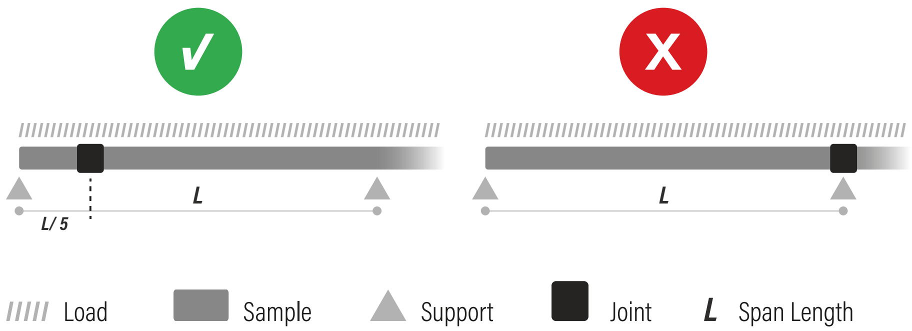


FIGURE 8

Recommended (left) and forbidden (right) joint locations.

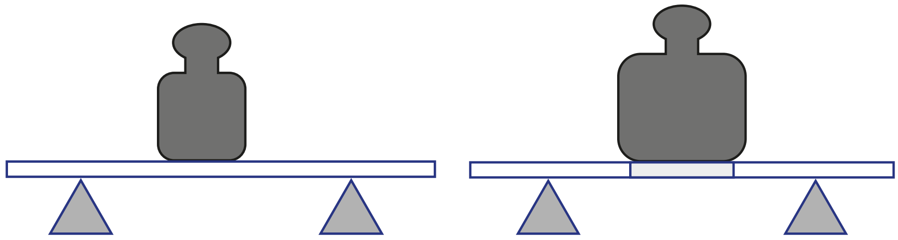


FIGURE 9

The single-span system (jointless) carries a smaller load than the multi-span system (jointed). The exact load shall be checked with the manufacturer or a responsible vendor. 50% of a multi-span (jointed) system's capacity is considered to be a sophisticated estimation.

TEMPERATURE CHANGES

In addition to static and dynamic loading, the impact of temperature must be considered in design and installation, especially where the temperature is known to vary significantly. The dimensions of all materials fluctuate with temperature. Temperature increases lengthen materials and decreases shorten. The length variation of the cable management system due to temperature variation must be considered as the cable management systems are often long, and hence thermal expansions may be significant.

Material	Thermal expansion coefficient [10^{-6} $^{m}/_{(m\,°C)}$]	One meter's expansion due to	
		ΔT=20°C [mm]	ΔT=100°C [mm]
Aluminium	21...24	0.42...0.48	2.1...2.4
Gray Cast iron	10.8	0.22	1.08
Cement	10...11	0.20...0.22	1...1.1
Concrete	13...14.5	0.26...0.29	1.3...1.45
Copper	16...17	0.32...0.34	1.6...1.7
Gold	14.2	0.28	1.42
Plastics	40...120	0.8...2.4	4...12
Stainless steel, 304 (austenitic)	17.3	0.35	1.73
Stainless steel, 316 (austenitic)	16.0	0.32	1.6
Stainless steel, 410 (ferritic)	9.9	0.20	0.99
Steel	11...12.5	0.22...0.25	1.1...1.25
Zinc	30...35	0.6...0.0	3...3.5

TABLE 1

Thermal expansion coefficients of some materials and length changes of a 1-meter bar due temperature changes of 20°C and 100°C.

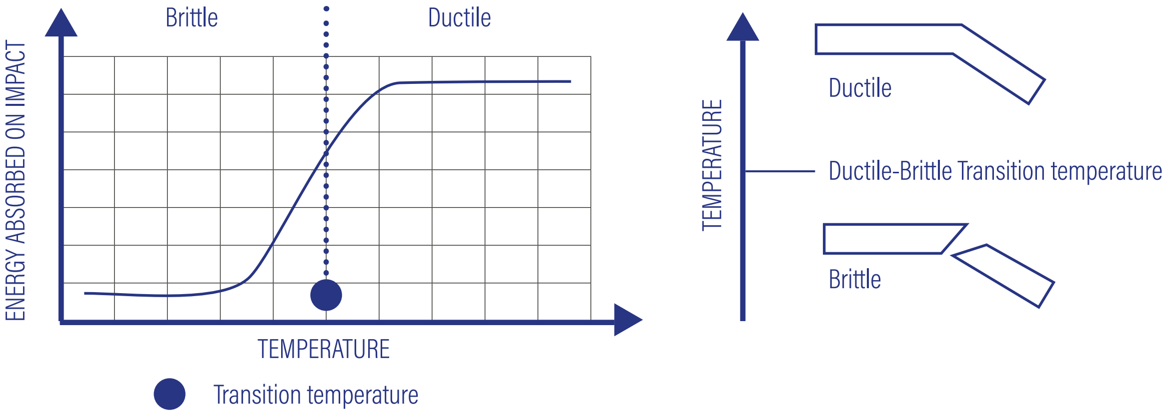


FIGURE 10

Many steels have a ductile to brittle transition temperature. In practice this means that steels, which are ductile and bend in warmer temperatures, are transformed to become brittle below a certain temperature. They then crack instead of bending and they are particularly sensitive to impacts.

Table 1 presents the thermal expansion coefficients of some materials. The table also shows examples of temperature change's impact on a 1-meter long bar in the concerned material. For example, because a 1-meter bar made of stainless steel (316) lengthens 0.32 mm due to +20°C temperature increase, it would extend 0.96 mm due to a temperature change from -20°C to +40°C, and a 6-meter bar would extend 5.76mm due to same temperature change. In general, the smaller the thermal expansion coefficient, the smaller the thermal expansion.

In addition to temperature variation, temperature itself may have an impact on the behavior of a material. Extremes of higher or lower temperatures are more likely to change the properties of any materials. Although this is more common with plastics, steel also suffers due to temperature variations. Steel's strength and modulus of elasticity decrease with temperature variations are remarkable at temperatures higher than +200°C. [1] At normal ambient temperatures (0…+40°C) the steel strength and flexibility can be considered as a constant. In extreme conditions, especially in a fire, the decline of steel's strength and increase of deflection must be considered. At high temperatures, steels stretch until they collapse. The exact physical properties of the chosen steel should be checked with the steel manufacturer case by case. For example, some stainless steel types may tolerate higher temperatures than structural steels.[2] Just like steel, aluminum alloys become weaker as the service temperature rises. Aluminum's strength and modulus of elasticity decrease with temperature are significant far before its melting point, which may be as low as +500°C. Just like steel, the properties of aluminum alloys variate a lot, hence accurate calculation should be done in accordance with the concerned aluminum alloy.

Beyond higher temperatures, lower temperatures are also able to have a significant impact on a material's properties. Many steels become stronger at cold ambient[3] and hence strength itself is not an issue at reasonable temperatures. Just like steel, aluminum alloys also tolerate cold temperatures well and their properties do not change much within a reasonable temperature range. Aluminum alloys have one benefit when compared with steels, as they do not have a ductile to brittle transition temperature, i.e. aluminum remains ductile until cryogenic temperatures. Instead, most steels transform from ductile to brittle at a certain temperature. At this point, steels cease to bend but instead begin to crack rapidly. (See: Figure 10) Impacts are especially disastrous for brittle steels, e.g. one root cause for the rapid sinking of the Titanic is assumed to be the brittle fracture due to collision with an iceberg[4] Brittle fractures happen without prior plastic deformation and at extreme speed, hence, can be a disastrous phenomenon

[1] *Outinen J. & Mäkeläinen P. 2002. Mechanical properties of structural steel at elevated temperatures and after cooling down. Second International Workshop << Structures in fire >>, Christchurch.*
[2] *Specialty Steel Industry of North America. Chemical compositions for common stainless steels. Education, Technical Resources, Composition/Properties.*
The European Stainless Steel Development Association 2012. Stainless steels at high temperatures (Materials and Applications Series, Volume 18 Stainless Steels at High Temperatures). ISBN 978-2-87997-064-6
[3] *Total Materia 2001. Steel properties at low and high temperatures.*
[4] *Bassett V. 1998. Causes and Effects of the Rapid Sinking of the Titanic. University Of Missouri-Rolla 1997 Testing Shows Titanic Steel Was Brittle.*

in certain applications. The transition temperature of steel depends on many factors; hence the transition temperature of any particular steel must be checked during design. As aluminum does not have a transition temperature, aluminum alloys represent an important class of structural metals for subzero-temperature and cryogenics applications.

CABLE INSTALLATION

Many installation parameters must be considered when cables are installed into the cable management systems, e.g. the maximum pulling tension, sidewall pressure, clearance, bending radius, and jamming. These parameters and their requirements may vary across different installations, such as aerial and buried.[5] The installation of cables is comprehensively defined in cabling standards, which have been developed over the years to ensure consistency of the installation quality. Alongside the cabling standards, some topics and factors of the cable installations are manufacturer-specific, such as cable bend radius and component assembly details. Therefore, the installation of cables should be completed in accordance with the latest versions of the relevant cabling standards, local regulations, and cable datasheets. Unclear issues should be resolved in coordination with the cable manufacturer and authorities to ensure the safe and valid installation of cables, as small details can make the difference between a successful installation and damaged cabling.[5]

Some important topics concerning cable installations are [6] :

1. Different cables, such as IT-cables and main power cables, should be segregated. (See: Figure 11)
2. Cables should be fastened to the cable ladder or tray to prevent movement of cables in all conditions and cases.
3. Stress on the cables should be eliminated.
4. The minimum bending radius of the cable should be in accordance with the specification

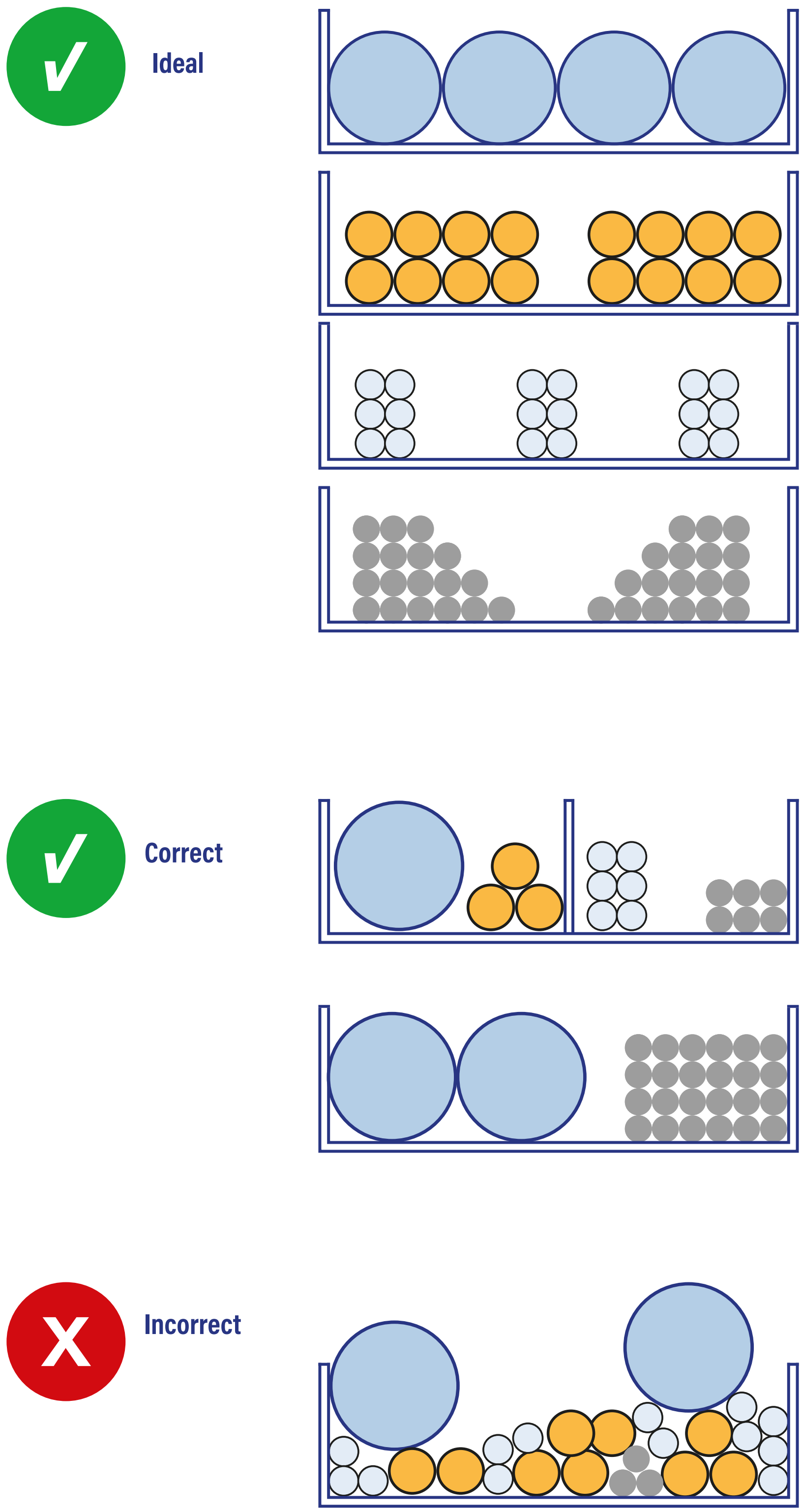


FIGURE 11

Correct, ideal and incorrect cable installation examples. Different cable types should be segregated.

[5] Southwire Company 2005. Power Cable Installation Guide.
[6] Nexans 2014. General Installation Guide.

of the manufacturer or the relevant product standards.
5. Tensile loads applied to cables or cable bundles should be in accordance with the specification of the manufacturer or the relevant product standards.
6. Pressure marks on the cable should be prevented.
7. Cable management systems are not intended for use as a ladder or walkway for people.
8. Cable management systems should not be overloaded.

MAINTENANCE

The maintenance of the cable management system is mostly carried out during design and installation. The first and the biggest aspect of maintenance is the choice of the cable management system's material and coating (surface finish) to ensure suitable corrosion resistance within the intended environment. By choosing the correct corrosion resistance for the intended environment the cable management system will fit its purpose over the designed lifetime. The second step is to design the cable management system for the intended load, i.e. the designer must know the intended cable load before purchasing the cable management system. Underloading is always safe, with the only downside being increased initial expense. Initially oversized (underloaded) systems allow the possibility to add cables and accessories later, for example, to add new cables during an extension to the building. Inversely to underloading, overloading is always harmful. At a minimum, overloading will wear the system and cause the need for maintenance, and in the worst case, the cable management system may collapse. Overload with dynamic loading (vibration) is always a particularly significant concern. The third maintenance step is the installation of the cable management system and the installation of cables. When this is completed properly, the cable management system generally does not require much maintenance work.

Visual inspection is often enough maintenance activity for cable management systems. At first, all couplings, joints, and fixings should be cross-checked to avoid falling accessories or components and to maintain the designed stability of the system. The systems should also be checked for the appearance of any corrosion, especially in locations where two different materials are in contact, i.e. where the possibility of galvanic corrosion exists. The third target of the visual inspection should be the extraordinary articles in the cable management system as they can cause extra loading as well as galvanic corrosion. The final target of a visual inspection is broken components, e.g. broken welds or rungs.

If the cable management system is damaged, for example, welding is broken or a side rail is deformed, all free parts or extraordinary articles should be removed immediately to avoid personal injuries due to falling articles. Following this, the root cause of the damage should be investigated to avoid new and continuous damages. When the root cause is found, corrective action should be executed at the earliest convenience by skilled workers. All maintenance activities should be completed by skilled workers to ensure safety and avoid additional damages. Local repairs are not recommended in any circumstance. Instead, the damaged section, e.g. one cable ladder, should be replaced by a new one to ensure the safe operation of the cable management system in the future.

It is recommended that any inactive or dead cables are removed from the system to improve the ventilation of the remaining cables. Removed cables also liberate load carrying capacity for any future extensions. Electrical equipment, cables, and wires may need periodical maintenance. Scheduled and required activities must be confirmed by the operator or cable manufacturer.

EARTH PROTECTION AND EMC

The primary target of earthing is to minimize the contact voltage where any fault occurs. In addition to minimizing the contact voltage, earthing creates a safe and controlled path for any unintended current to earth, enabling the operation of all protection equipment to function as designed if any fault occurs. Earthing also prevents voltage difference, and hence sparking and arc, between different parts. Though many functions of earthing are for occupational safety, earthing protects telecom and IT systems by preventing interference. The stress to the connected devices' insulation due to potential differences is removed through proper earthing, and therefore the lifetime of connected devices is extended.

Earthing is divided into protective earthing (PE) and functional earthing (FE). Protective earthing is composed of a grounding electrode, the main grounding rail, and a grounding wire between them. The main grounding rail is normally located close to the power center unit. Functional earthing secures the operation of devices connected to it. IT devices especially often need a reference voltage close to earth potential (=zero potential) and therefore they have a separate earthing cable. The cable for functional earthing should have its own color, e.g. black, and the color of the protective earthing's cable (yellow-green) should not be used for functional earthing. It is recommended to conduct the cable management system's earthing from both ends of the system to ensure proper earthing in situations where the cable management system is disconnected.

It is important to mark earthing separately from the potential equalization. The purpose of potential equalization is solely to bring the electrical potential of connected metallic parts to the same level and therefore prevent current flow between them. I.e. potential equalization does not automatically mean zero potential. Earth connection and zero potential happens if the main potential equalization system is connected to the protection earthing system with the main earthing rail.

In Finland SFS 6000 *(Pienjännitesähköasennukset)* and ST 53.21 *(Rakennusten sähköasennusten maadoitukset ja potentiaalitasaukset)* define the requirements for earthing and potential equalization. The earthing is important and it must be completed carefully to avoid hazards such as those presented in

Tukes' (Finnish Safety and Chemicals Agency) accident report 2014-0091 related to electric shock from a poorly earthed cable ladder. [7)]

Electromagnetic compatibility (EMC) is the ability of device, equipment, or system to operate satisfactorily in its electromagnetic environment without introducing malign electromagnetic disturbances to anything in that environment, i.e. devices can operate close to each other without mutual magnetic interferences.[8)] This topic is covered on a directive 2013/35/EU and standard EN 50174-2, which presents the risks arising from electromagnetic fields, and technical advice to avoid electromagnetic interference (EMI). In Finland, government decree *(Valtioneuvoston asetus)* 388/2016 sets levels for magnetic fields to protect employees from negative effects.

The cable management system improves EMC performance if its earthing and potential equalization are in order. If not, then the cable management system impairs EMC performance. Fortunately, the cable management systems often form the ground (zero potential) automatically, if they are installed correctly. Therefore, the cable management systems perform as a shielding structure for the enclosed electronic system. It's worth mentioning that a specific EMC test method is not available for the cable management system[9)], and therefore the validity can be justified via a range of test methods. For example, both IEC 62110 and EN 50413 present methods to measure electric and magnetic fields.

FIRE-RESISTANT INSTALLATION

In Finland, new construction production is guided by *Ympäristöministeriön Suomen Rakentamismääräyskokoelmat* (eng. Ministry of Environment's collection of building regulations), in which section E 'Buildings' fire safety, regulations and instructions' provides the fire safety requirements. Though the collection is intended for new construction projects, it can be considered in renovation processes if not otherwise stated. In addition to section E, there is a range of standards, regulations, and instructions related to fire safety in Finland, starting from *Pelastuslaki* 29.4.2011/379 (Law of rescue) and ending with *ST-käsikirja 39 Kaapelit ja paloturvallisuus* (ST-manual 39 Cables and fire safety). In addition to previous documents, SFS 6000 -series and ST 51 -series are worth consideration when designing fire-resistant construction projects in Finland. In Europe documents considered important in the concerned field are ISO 24679-1 Fire safety engineering, Eurocode EN 1993-1-2, and 305/2011/EU Construction Products Regulation *(Rakennustuoteasetus).*

As generally expected, the design and installation of fire-resistant cable management systems are covered by a range of regional standards, such as SFS 6000-5, EN 1363-1, EN 1366-11, DIN 4102-12, and NPR 2576.[10)] Regional standards are complemented by many regional regulations, laws, and instructions. Different systems, e.g. emergency lights, fire-extinguishing systems, smoke ventilation, etc. may be covered by different standards and regulations, or at least they may have their own sections within generic standards. In addition to manifold regulations, construction companies and operators may declare their own specifications for fire-resistant components and systems installed within their buildings. Therefore, the cable management system manufacturer, responsible vendor, developers, and building operators should check the fire resistance requirements collectively case by case to ensure that the chosen cable and cable management system meets requirements and are safe for their planned purpose.

The main principle is that the cable management systems must support cables with intrinsic fire-resistance and enable them to maintain their functionality for a specified period while exposed to fire. In other words, the ensemble of all components from the power source to the end product's connector (cables, ladders/trays, supports, accessories, housings, boxes, connectors, screws, etc.) should maintain their ability to operate for a specified period while exposed to fire. Where this is achievable the system can be said to be fire-resistant during a defined period. Any situation where only the cable ladder or tray withstands the fire and cable doesn't would be dubious.[11, 12)]

So that the entire cable management system (incl. cables) could be said to stand heat and fire for a certain time, the entire cable management system should be tested with electricity. When the metallic components are burnt together with powered cables, it is possible to identify the weakest component as well as the specified period spent exposed to fire. As sometimes the cable loses its functionality, sometimes metallic components collapse, by testing the system comprehensively any potential for speculation is removed. Through utilizing this method of testing it is possible to declare the reliable fire-resistance capacity of the system. This approach is in accordance with the technical report CLC/FprTR 50658 *"Cable management systems (CMS) providing support for cables with intrinsic fire resistance"*, which is planned to be the European standard for fire-resistant cable management systems. The technical report concerned specifies test methods for cable management systems to determine their ability to maintain the function of carried cables for a specified period when subjected to fire under defined conditions. The technical report concerned is only currently a recommendation, as it has not been awarded a 'standard' status yet, however, it is in the approval phase.

Just like the technical report CLC/FprTR 50658, many regional cable management fire safety standards, like DIN 4102, also refer to standard ISO 834-1, Fire-resistance tests, when the basics of the fire tests are considered. For example, many regional standards require the use of the temperature curve given in ISO 834-1: *Temperature [°C] = 345 * log10 (8 * time [min] + 1) + 20*. In practice, this means that furnace

[7)] *Tukes, Vaurio- ja onnettomuusrekisteri VARO 2014. 2014-0091: Asentaja sai sähköiskun maadoittamattomasta kaapelihyllystä.*
[8)] *electronics-notes.com. What is EMC: Electromagnetic Compatibility Basics.*
[9)] *Hasselgren L. & Nilsson U. 2015. On the EMC Performance of Cable Trays. Electronic.se*
[10)] *Lepistö A. 2015. Palonkestävät johtojärjestelmät. Metropolia Ammattikorkeakoulu.*
[11)] *Virta S. 2018. Palonkestävien johtojärjestelmien suunnittelu. Oulun ammattikorkeakoulu.*
[12)] *Heikkinen J. 2012. Palonkestävät sähköasennukset ja suunnittelu. Metropolia Ammattikorkeakoulu.*

Shortest length of time circuit integrity is maintained, in minutes	Class
30	E 30
60	E 60
90	E 90

TABLE 2

Circuit integrity classes according to DIN 4102-12.

temperature must be 576°C after 5 minutes and 945°C after 60 minutes because temperature follows the relationship of a logarithmic curve as a function of time. Hence, most of regional fire safety standards will provide similar, comparable results, if cables and electricity are implemented into the test. It is then possible to provide the minimum time that circuit integrity will be maintained for. (See: Table 2).

Cable management system

As pointed out in the "Installation – Temperature changes" chapter, enormous heat weakens steel. Therefore, when exposed to fire the main challenge for the cable management system is its mechanical transformation. The cable supports bend significantly and the support of the cables disappears, and the cables extend. (See: Figure 12) Eventually the cables will be stretched enough to cut the power off, causing a blackout.

To maximize the cable support in a fire, both the span and the maximum allowed load are often limited. The maximum span and the maximum allowed load of a particular fire-resistant cable management system shall be confirmed by a responsible vendor or the manufacturer. In general, a 1.5 m span is used as the maximum allowed span for fire-resistant installations, and a 20 kg/m load capacity, when exposed to fire, is considered a good result.

In fire-resistant cable management systems, standard cables should not be placed next to fire-resistant cables. If they need to be placed on the same ladder or tray, they should be separated. Critical cable management systems, such as safety systems' power supply cables, should be installed in the highest position, above any other assemblies, so that collapsing structures do not cause additional loads to the critical cable management system. In vertical assemblies, the cables should be clamped every 300 mm and there should be either a fire stop or a 300 mm long horizontal section placed every 3500 mm.

Cables

Another technical challenge in enormous heat is the behavior of cables. The temperature increase in the cable may decrease the voltage in the system due to copper's increased resistance. The voltage decrease may be enough to cut off connected equipment in a fire. To avoid blackout due to fire, cable cross-section should be designed two size classes bigger in fire-exposed applications than in normal applications. Copper cables generally perform better within fire-exposed scenarios than aluminium cables due to the higher melting point of copper.

Fire-resistant cables can often be identified from the FRHR (Fire Resistant Halogen Free) mark. The color of this cable type is normally orange or red. The most reliable method to confirm the suitability of the cable to significant heat is to review the cable manufacturer's datasheets. Normally fire-resistant cables are mineral-insulated in accordance with IEC 60702-1 and 60702-2, or the cable manufacturer has tested the cables in accordance with EN 50200, EN IEC 60331-1, and EN 60332-1-2..[12]

Fire-resistant cables, which are used in systems exposed to fire in order to maintain power, must operate as long as defined and the cable must not enable the fire to spread. Critical cables must be installed within a separate ladder or tray, or they must be separated from other cables. It is also wise to review any changes in the length of the cables due to mechanical changes in the system during a fire. Fire-resistant cables must be halogen-free to avoid the formation of poisonous gas during a fire.[13]

SUSTAINABILITY

Sustainability and environmental issues are an essential part of Meka Pro's corporate culture. Meka Pro complies with ISO 14001, and in addition to that considers sustainability more widely. In production, high-quality raw materials are used and material flows are controlled. All waste materials (incl. rolling fluids) are recycled properly. Energy consumption is also controlled, and new methods are continually searched for to increase energy efficiency. In addition to materials and energy, also employees' well-being and work ergonomics are taken care of.

High-quality raw materials, efficient production, and careful design provide products that are easy to install and carry higher loads when installed. The strong and verified load capacity of Meka Pro's products enables the minimization of the number of ladders and trays required during installation, which in turn improves the efficiency of transportation. Easy installation and verified load capacity together with proper corrosion protection and high quality provide a

[13] *Virta S. 2018. Palonkestävien johtojärjestelmien suunnittelu. Oulun ammattikorkeakoulu.*

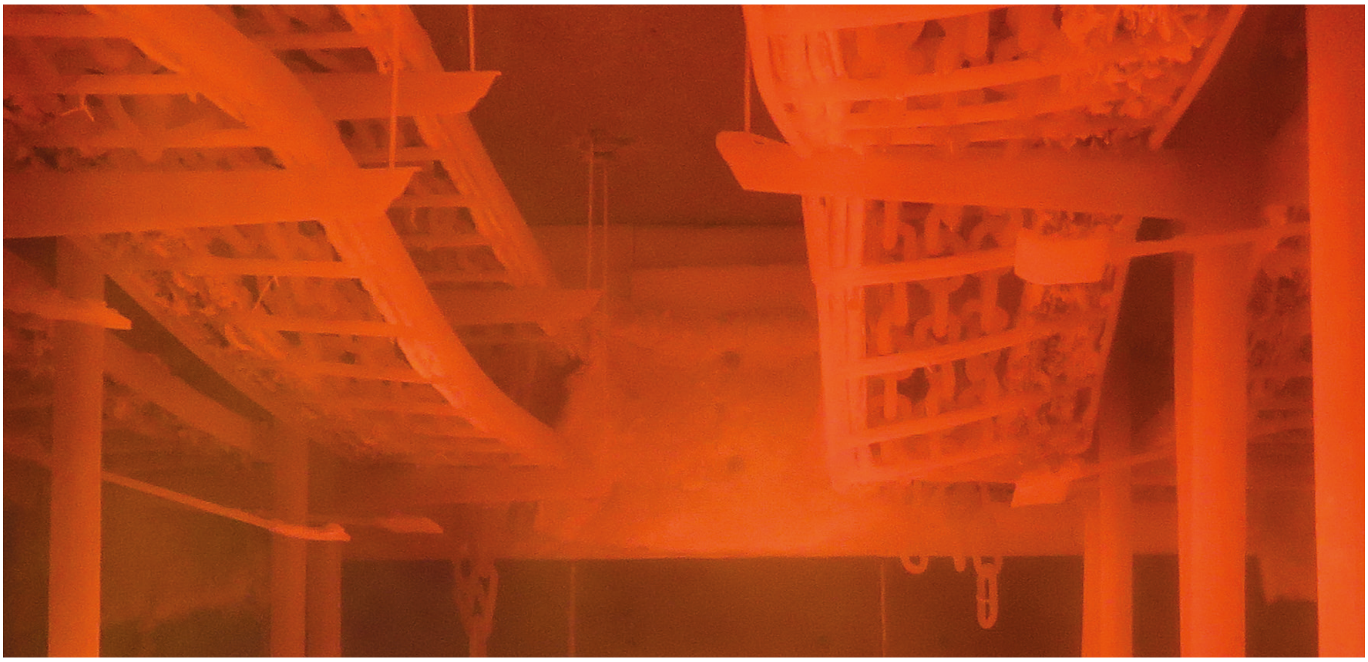


FIGURE 12

Fire resistance test of the cable ladder. With the temperature reaching 950°C after 60 minutes the supports and ladders have already bent noticeably.

long product lifetime for Meka Pro's products. Therefore, energy consumption and waste are also minimized for not only Meka Pro but also the end-user.

The protection of human health as well as the environment from the risks posed by chemicals has improved in the EU with REACH, regulation (EC) No 1907/2006 of the European Parliament and Council. The concerned regulation (Registration, Evaluation, Authorization, and Restriction of Chemicals) applies to all chemical substances, not only those used in industrial processes. Therefore, the regulation has an impact on most companies across the EU and enhances the competitiveness of the EU chemicals industry. To comply with the regulation, companies must identify and manage the risks linked to any chemical substances they manufacture and market in the EU. Companies must also demonstrate how their substances can be safely used, and they must communicate the risk management measures to the users. If a company does not comply with REACH, authorities can restrict the use of their chemical substance. Meka Pro completely fulfills all of its responsibilities under REACH regulation.

Other important environmental directives regarding hazardous substances and the waste of industrial products within the EU

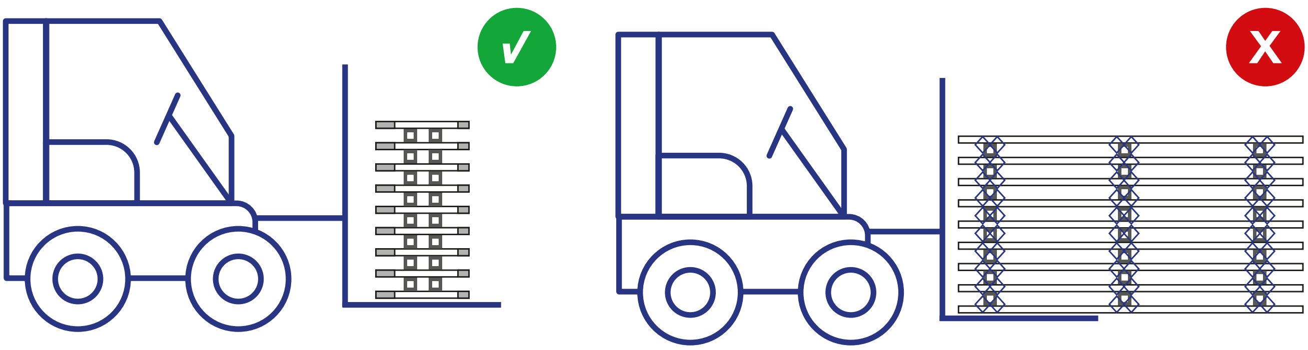


FIGURE 13

Products should be treated with care, for example, lifting should always be carried out from the sides. Lifting should never be carried out from the end of the package.

FIGURE 14
Proper personal protection must be worn to prevent all possible injuries whilst working with the cable management systems.

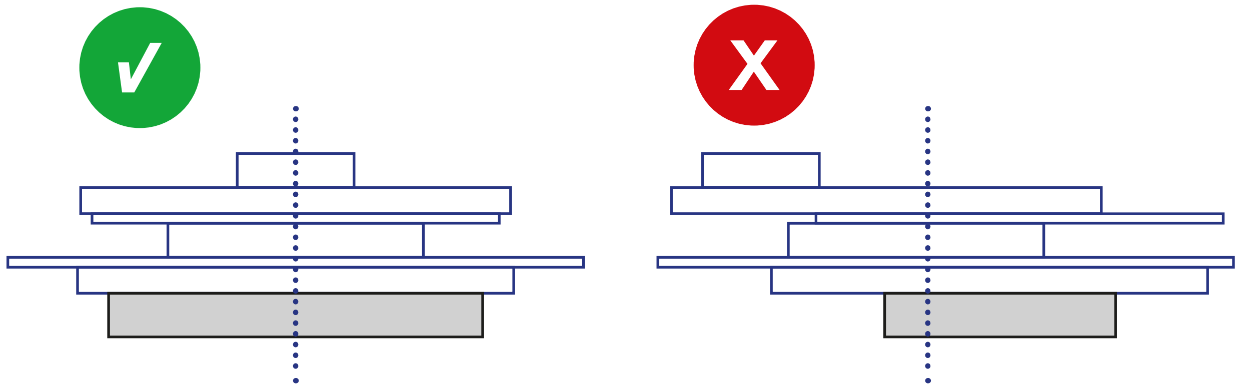


FIGURE 15
The bundle's center of gravity should be in the centre.

market are RoHS 2 (Directive 2017/2102) and WEEE (Directive 2012/19/EU). The restriction of hazardous substances in electric and electronic equipment (RoHS 2) restricts the use of certain hazardous substances (e.g. Cadmium, Lead, and Mercury) in electric and electronic equipment. Waste electrical & electronic equipment (WEEE) requires manufacturers of electrical and electronic equipment who sell their products in the EU to arrange a recycling program. Although the cable management systems are not included in the scope of RoHS 2 and WEEE, Meka Pro as an environmentally conscious company operates in accordance with the spirit of those directives. Meka Pro's cable management systems do not contain hazardous substances and Meka Pro's products can also be fully recycled.

Meka Group implements the ISO 45001 standard for occupational health and safety. Meka Group prioritizes both physical and mental wellbeing, with all employees sharing responsibility for monitoring conditions, especially immediate supervisors. Group occupational health and safety principles, roles, and responsibilities are outlined in a regularly updated action plan. Focus lies in maintaining employee health and preventing accidents and illnesses. Internal inspections and safety rounds contribute to monitoring occupational health and safety. Safety card training is mandatory for all employees. 6S rounds enhance continuous safety improvements. Safety observations are reported and addressed immediately to supervisors. All observations are also discussed in operational meetings, with thorough investigations into incidents and near-misses in order to take preventive actions.

HANDLING

All of Meka Pro's products are appropriately packed for any mode of shipment, only long sea transports of pre-galvanized (PG) products require special attention. The most important factor is the steady handling of packages in order to avoid injuries and product damage throughout the entire transportation chain, from the factory to the final installation. Only proper equipment should be used during transportation and all equipment used in transit must be properly secured to prevent the movement of any packages. On the construction site products should only be handled with suitable mechanical equipment. At every stage of transportation the safety limits of the equipment must be known and packing all equipment must have the capacity to support the package(s). In all situations packages should be lifted from the side and never from the end. (See: Figure 13) During every stage proper personal protection must be worn to prevent all possible injuries. (See: Figure 14)

PACKING

All of Meka Pro's products are appropriately packed for any mode of shipment and only long sea transports of pre-galvanized (PG) products require special attention. If repacking is needed, it should be done with care to avoid injuries and product damage.

Long, straight products, such as ladders and trays, should be packed in bundles. The center of gravity should be in the bundle's center to ensure a stable package. (See: Figure 15) Depending on product length, products or bundles should be supported with an adequate number of transverse rungs to provide sufficient clearance for the forklift

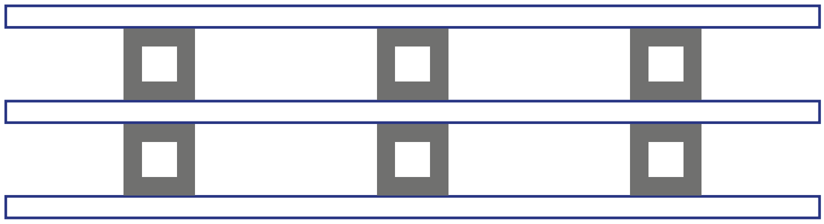


FIGURE 16

Transverse rungs between products are recommended to provide sufficient clearance for transportation.

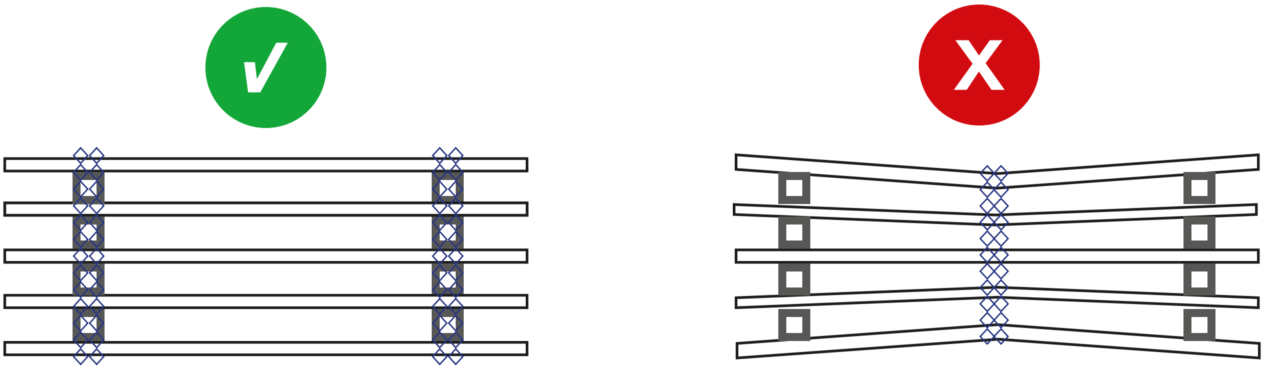


FIGURE 17

Bundles should be tied by non-metallic bands on transverse rungs to avoid rust stains and excessive deflection.

truck's forks. (See: Figure 16) The packages are recommended to be tied by non-metallic bands to avoid rust stains forming on products and the contamination of stainless-steel products. Bands should be positioned on transverse rungs to avoid excessive deflection and hence pointless damage to the end product. (See: Figure 17)

Shorter and smaller parts, such as fittings, should be packed to a suitably sized pallet to enable forklift truck usage. Each product or package (box, bag) should be wrapped to secure the parts from damage.

STORAGE

The storage of the cable management system's components depends on the material, coating, and packaging. Of course, all products will ideally be stored in a dry place under a roof whenever possible. As roofed storage is not always possible or profitable, the following chapters present the main principles and suitable environments to maintain components in their delivered condition during storage. As a general instruction, the storage area should be reasonable and located so that extra handling is minimized. Each activity causes extra stress to the components and is a potential source of damage. In general, all products should be stored in a safe manner to avoid injuries and product damage during storage and transportation.

Bath hot-dip galvanized (HDG), stainless steel, and non-metallic products can be stored outside without covering if internal storage is not feasible. Stainless steel products must be separated from other steel types. Though these materials can be stored outside, drainage must be secured to avoid pooling of any water, which accelerates oxidation and may cause storage stains. Water pooling can arise from condensation if the temperature of the steel is lower than the dew point of the ambient environment. The condensation process may also happen if there is high humidity in the storage location. Rising water may also cause harm, hence the packages and products should be stored at least 30 cm above ground level to reduce this possibility and to improve air circulation. (See: Figure 18) One method to avoid water pooling and ensure runoff is to elevate one end of the package slightly above the other. (See: Figure 18) A waterproof cover, which allows air circulation, is always beneficial. Moisture and poor air-circulation can expose galvanized products to white, black, and intermediate gray corrosion, which is referred to as storage stain.[14]

[14] *Worldwide Steel Buildings. Storage stain.*

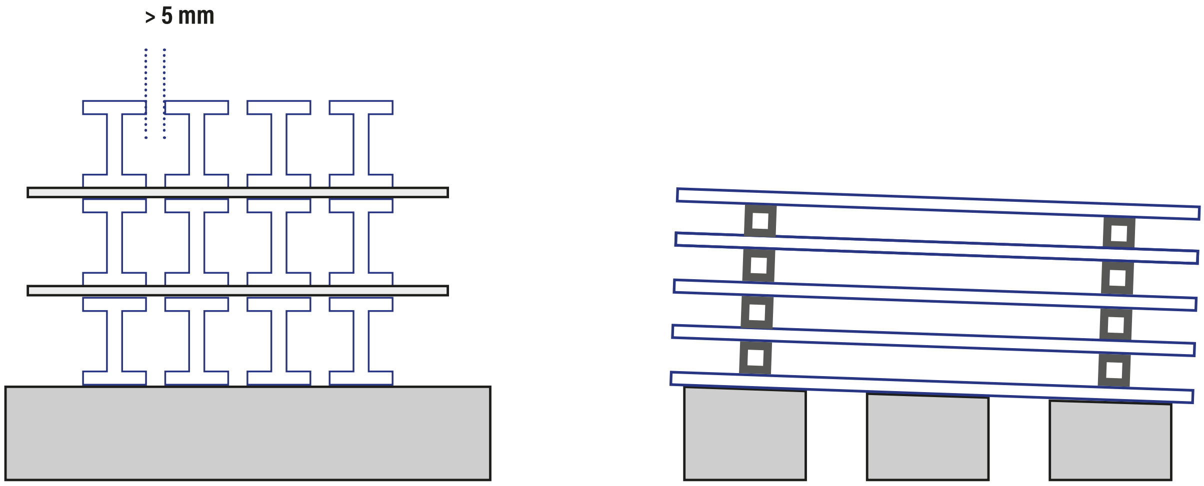


FIGURE 18

Proper storage of the cable managements system's components is at least 30 cm above ground level and slightly inclined.

Storage stain generally affects galvanized products, particularly freshly galvanized steel articles, which do not have the protective zinc carbonate. Zinc carbonates are the main components of the zinc patina, a thin corrosion protection film on the zinc surface.[15] If the freshly galvanized steelwork is exposed to moisture and poor air circulation, the zinc reacts with moisture and forms zinc hydroxide, which accelerates zinc corrosion and forms wet storage stains.

Growth of wet storage stains (white rust), stops when the moisture is removed, and air circulation is improved. Small amounts of white rust will disappear by itself, and all white rust can be removed chemically or mechanically by brushing or washing.[16] White rust may look alarming because its volume can be 100-500 times bigger than zinc volume.[17] However, its impact on the lifetime of corrosion protection is often negligeable except in electro-galvanized products wherein it may be harmful due to the thinness of the zinc coating. If the circumstances are not changed, and moisture still exists with poor ventilation, white rust will initially turn to a black and finally red dust. White rust alone is not a reason for reclamation in accordance with the standard of hot-dip galvanized coatings ISO 1461.[18]

Pre-galvanized (PG) and aluminum products should always be stored under a roof in a dry and ventilated location to ensure both appearance and corrosion protection of the products. The possibility of water pooling should be eliminated in these packages. Packages should be loose enough to ensure air circulation and prevent storage stains.

All products packed to bags, boxes, cartons, or similar must be stored under a roof in a dry and ventilated location to ensure appearance, functionality, and corrosion protection of the products. All packed products are recommended to be kept in packages until installation to avoid incorrect installation. Whilst products may look similar their strengths or corrosion protection levels may be different. The packaging makes it possible to identify products and detect their differences and therefore avoid incorrect installation.

[15] *Galvanizers Association of Australia. Wet Storage Stain (White Rust)*
[16] *Leino T., Häkkä-Rönnholm E., Nieminen J., Koukkari H., Hieta J., Vesikari E. & Törnqvist J. 1998. Teräsrakenteiden käyttöikäsuunnittelu. VTT Tiedotteita – Meddelanden – Research notes 1937.*
[17] *Hirn A. 2019. Galvanizing Handbook. Nordic Galvanizers.*
[18] *Hirn A. 2019. Galvanizing Handbook. Nordic Galvanizers.*

MATERIAL PROPERTIES AND THEIR IMPACT

The chosen material and its coating form both the appearance and corrosion protection of the cable management system. Hence the choice of both material and coating is an essential part of the system design to ensure sufficient lifetime and aesthetic of the system within the intended environment. Although aesthetics are important, the focus should primarily be on corrosion protection, as an installed cable management system's maintenance against corrosion is often impractical. Corrosion protection must be considered whilst designing the system by choosing materials and coatings in accordance with the intended environment. By choosing the correct material and coating, cable ladders and cable trays manufactured by Meka Pro can be applied to all applications and environments.

ENVIRONMENTS

Corrosion is the destructive attack of a material by reaction with its environment. Hence, the role of the environment is obvious in the corrosion process, e.g. the corrosion process accelerates as temperature rise. Other climatic factors are relative humidity and pollution. Normally relative humidity must be more than 60% for the corrosion process to begin. In Finland, external relative humidity is almost always more than 60 %. Nitrogen oxides are an example of pollution that can exaggerate the corrosion process. Any dirt on the material surface is particularly unfavorable for corrosion protection, as it prevents drying of the surface and may act as an electrolyte in the corrosion process.

Table 3 shows the corrosivity categories and examples of indoor and outdoor environments in accordance with ISO 12944. As shown in the table, steel thickness loss in a heated living room is less than 1.3 µm/year, whereas next to a swimming pool it can be as much as 80 µm/year. Corresponding zinc losses would be 1.3 and 4 µm/year, which is strong evidence of zinc's efficiency in corrosion protection.

Table 4 shows the classification for resistance against corrosion in accordance with the standard IEC 61537. The table lists the most commonly used finishes and materials, which can be used as a reference against other finishes and materials, which are measured for classification purposes. The compliancy for different classes is checked either by measuring the zinc layer thickness according to ISO 2178 or ISO 2808 or by carrying out a neutral salt spray (NSS) test according to ISO 9227 over a particular period. If the salt spray test is carried out, the sample will pass the test if the corrosion of the surface has not exceeded rating 4 of ISO 10289.

Contrary to the ISO 12944, IEC 61537 does not commit itself with different corrosion environments nor give any references to the annual material losses. Only reference materials are given, and the user must decide whether the reference material meets his requirements in the intended environment or not. As a reference, Table 5 presents Meka Pro's products classified according to both standards of ISO 12944 and IEC 61537.

The acidity or alkalinity of the environment also impacts the corrosion behavior of materials. The acidity of a water-based solution is defined by pH. When the pH of the liquid is less than 7, the liquid is acid, and when the pH is greater than 7, the liquid is alkaline. The liquid is said to be neutral when the pH is 7. Neutral liquid (clean water) has one hydrogen ion (H^+) and one hydroxide ion (OH^-). Acid liquids have extra hydrogen ions (H^+), whereas basics have extra hydroxide ions (OH^-). Note that pH is a logarithmic scale, in which the change of one integer is a tenfold change in liquid's acidity or alkalinity. Examples of acids are nitric acid, sulphuric acid, and hydrochloric acid. Examples of alkaline are ammonia, calcium hydroxide, and sodium hydroxide.

Hot-dip galvanized steel is suitable for pH environments 6-12.5, whereas aluminum fits into pH environments of 4-8.5, i.e. aluminum tolerates better acid liquids, whereas hot-dip galvanized is stronger in basic liquids. Chloride causes pitting

Category Corrosivity	Informative examples of typical environments [19,20,21]	Low-carbon steel Thickness loss [µm/a]	Zinc loss per year [µm/a]
C1 Very Low	**Indoor:** Heated spaces with low relative humidity and insignificant pollution, e.g. offices, schools, museums **Outdoor:** Dry zone very low pollution and time of wetness, e.g. certain deserts, central Artic/Antarctica	≤ 1.3	≤ 0.1
C2 Low	**Indoor:** Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sport hall **Outdoor:** Temperate zone, atmospheric environment with low pollution (SO_2 < 5 µg/m^3), e.g.: rural areas, small towns. Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, sub-arctic areas	> 1.3 to 25	> 0.1 to 0.7
C3 Medium	**Indoor:** Spaces with moderate frequency of condensation and moderate pollution from production process, e.g. food-processing plants, laundries, breweries, dairies **Outdoor:** Temperate zone, atmospheric environment with medium pollution (SO_2: 5 µg/m^3 to 30 µg/m^3) or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides, subtropical and tropical zones with atmosphere with low pollution	> 25 to 50	> 0.7 to 2.1
C4 High	**Indoor:** Spaces with high frequency of condensation and high pollution from production process, e.g. industrial processing plants, swimming pools **Outdoor:** Temperate zone, atmospheric environment with high pollution (SO_2: 30 µg/m^3 to 90 µg/m^3) or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas without spray of salt water, exposure to strong effect of de-icing salts, subtropical and tropical zones with atmosphere with medium pollution	> 50 to 80	> 2.1 to 4.2
C5 Very High	**Indoor:** Spaces with very high frequency of condensation and/or with high pollution from production process, e.g. mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones **Outdoor:** Temperate and subtropical zones, atmospheric environment with very high pollution (SO_2: 90 µg/m^3 to 250 µg/m^3) and/or important effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline	> 80 to 200	> 4.2 to 8.4
CX Extreme	**Indoor:** Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from production process, e.g. unventilated sheds in humid tropical zones with penetration of outdoor pollution including airborne chlorides and corrosion-stimulating particulate matter **Outdoor:** Subtropical and tropical zones (very high time of wetness), atmospheric environment with very high pollution (SO_2 higher than 250 µg/m^3), including accompanying and production pollution and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas withoccasional contact with salt spray	> 200 to 700	> 8.4 to 25

TABLE 3

Corrosion categories according to ISO 12944.

[19] Hot Dip Galvanizers Association Southern Africa. 2015. Hot Dip Galvanized Information Sheet No.8: Corrosion of Zinc – Corrosivity of Atmospheres.
[20] SteelConstruction.info. Corrosion of Structural steel.
[21] Teräsrakenneyhdistys. 2014. Kuumasinkittyjen teräsrakenteiden käyttöikä.

Class	Reference – Metallic coating or Stainless steel
0[a]	None
1	Electro-galvanized to a min. thickness of 5 µm, or pre-galvanized to coating designation Z100 or Z140
2	Electro-galvanized to a min. thickness of 12 µm, or pre-galvanized to coating designation Z200
3	Pre-galvanized to coating designation Z275
4	Pre-galvanized to coating designation Z350
5A	Pre-galvanized to coating designation Z600
5B	Bath galvanized to a zinc, min. thickness of 45 µm
6	Bath galvanized to a zinc, min. thickness of 55 µm
7	Bath galvanized to a zinc, min. thickness of 70 µm
8	Bath galvanized to a zinc, min. thickness of 85 µm
9	Bath galvanized to a zinc, min. thickness of 110 µm
10	Bath galvanized to a zinc, min. thickness of 165 µm
11	Stainless steel manufactured to ASTM: A 240/A 240M - 95a designation S31603 or EN 10088 grade 1-4404 with a post-treatment [b]
II	Steel 1.4301 (304) and 1.4307 (304 L)
III	III Steel 1.4401 (316) and 1.4404/1.4435 (316 L)

[a] Note, figures are acc. to standards ISO 2081, ISO 4042, ISO 3575, ISO 4998, EN 10346, ISO 10684 and ISO 1461.

TABLE 4

Classification for resistance against corrosion in accordance with IEC 61537.

Galvanic corrosion

Galvanic corrosion is not possible:
- in metals with no electropotential difference
- with no electrical contact
- without an electrolyte

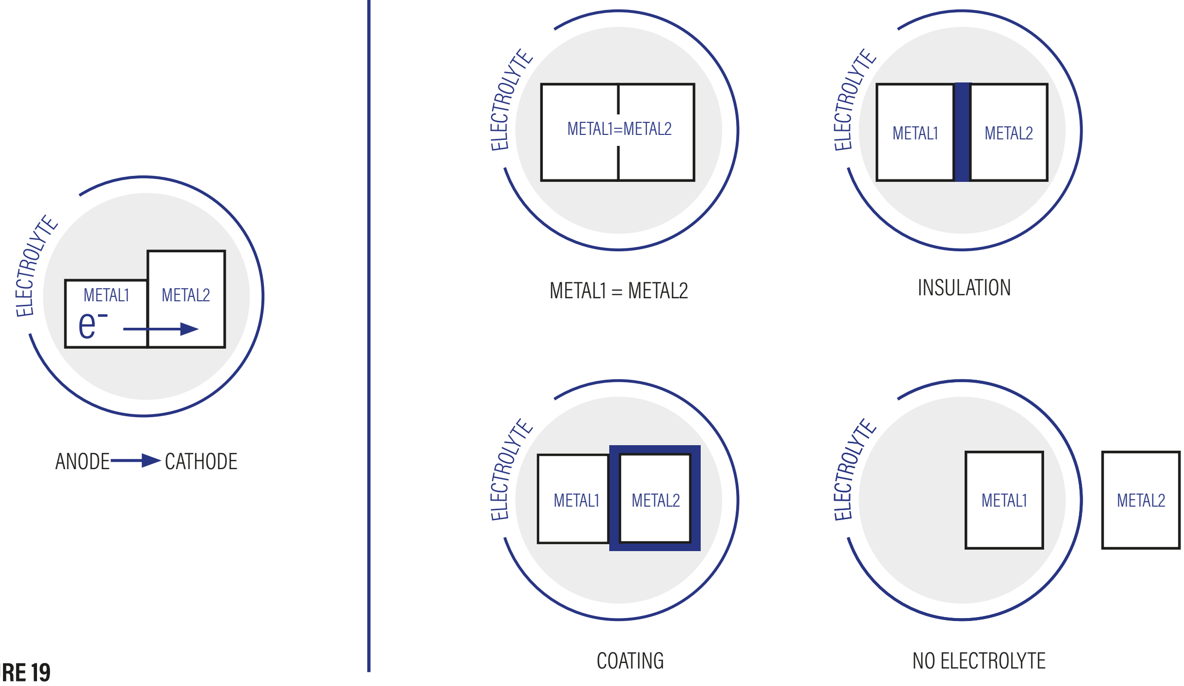


FIGURE 19

Galvanic corrosion and how to avoid it.

corrosion to aluminum, and sulphur dioxide and nitrogen oxides are a risk for the zinc coatings. Though the chromium contents of stainless steels make them strong against corrosion, they are not fully corrosion-free. Extreme pH values cause challenges to stainless steel too. Due to the broad supply of stainless steel, their corrosion sensitivity should be studied case by case. As a rule of thumb, it can be stated that molybdenum contents (HST) make stainless steel stronger against acids.

CORROSION

Corrosion is a natural process, which gradually destroys materials, normally metals, by chemical and electrochemical reactions in their environment. Two common corrosion types are chemical corrosion and galvanic corrosion. The phenomenon where materials dissolve directly due to a corrosive environment (liquids, acids, solvents, etc.) is referred to as chemical, or general, corrosion. This corrosion type destroys the material's surface evenly or locally in one area. The more common corrosion type is galvanic corrosion, which is a summary of electrical and chemical phenomena. Galvanic corrosion only happens where materials with different electrode potentials are electrically connected by electrolytes or a conducting environment. When potential difference and electrolytes are in place, the less noble material (anode) will corrode, and the precious metal (cathode) protects itself from corrosion. Figure 19 illustrates the process and methods to avoid galvanic corrosion. As shown, the prerequisite for galvanic corrosion disappears, if one factor is isolated from the process, i.e. galvanic corrosion is not possible if electrical connection, electrode difference, or electrolytes are eliminated from the system.

The galvanic corrosion rate depends on the electrical conductivity of the solution, the difference in electrode potential of the materials, and the surface ratio between the materials. Electrical conductivity together with pH-value has a major influence on galvanic corrosion's intensity and distribution of the corrosion. If conductivity is strong (e.g. seawater, sulphuric acid, or saturated sodium), galvanic corrosion is distributed widely on the surface. If the conductivity is weak (e.g. distilled water and supply water), galvanic corrosion happens near the materials' connection. The electrode potential is influenced by several factors, such as temperature, velocity, etc., with the only fluid for which these factors are documented comprehensively being seawater. A simplified version of the galvanic series is presented in Table 6. It's worth noting that the magnitude of electrode potential does not predict the corrosion rate, it only suggests that the less noble material (anode) will corrode faster.

The surface ratio is a very important factor in galvanic corrosion. The larger the cathode compared to the anode, the greater the galvanic current, and therefore, corrosion. This must be considered when materials are chosen. The less noble material should not be smaller if it is important for the application's functionality. In liquids, salinity, oxygen content, and flow rate influence the corrosion. Saltwater is an efficient electrolyte and therefore acts as an accelerator for corrosion. Flow helps corrosion by bringing more oxygen to the surface and carrying reaction products away. Often corrosion occurs slower when in deeper water due to the lower oxygen content. Corrosion in soils is dependent on a variety of factors, such as moisture content, mineral content, pH, oxygen availability, resistivity, and microbiological activity. These parameters may vary a lot across vertical and horizontal directions, alongside seasonal variations, and therefore corrosivity should be checked locally case by case.

Category ISO 12944	Meka products	Category IEC 61537
	Aluminum products: • Description of the material in Meka's product name: **AD, AL**	**N/A**
C1-C2	Electro-galvanized products with a coating thickness of 5-8 µm: • Description of the surface treatment in Meka's product name: **EG** Painted sheet metal products: • Description of the surface treatment in Meka's product name: **M, B**	**1**
	Pre-galvanized sheet metal products with a coating thickness of 20 µm: • Description of the surface treatment in Meka's product name: **PG**	**3**
C3-C4	Products bath hot-dip galvanized after manufacturing, with a coating thickness of 45-55 µm: • Description of the surface treatment in Meka's product name: **HDG** Products made of zinc-based special coated steel: • Description of the surface treatment in Meka's product name: **XPG**	**6**
C5-CX	Acid-proof products (AISI 316L / HST): • Description of the material in Meka's product name: **HST**	**III**

TABLE 5
Suitability of products made by Meka Pro to different corrosion classifications.

Noble metal (cathode)
Platinum
Gold
Silver
Stainless steel
Nickel
Monel (2/3 Ni, 1/3 Cu)
Aluminum bronze
Copper
Brass
Tin
Lead
Cast iron
Steel
Carbon steel
Cadmium
Aluminum
Zinc
Magnesium
Base metal (anode)

TABLE 6
Simplified galvanic series in salt water (+25°C).

ALUMINUM

Aluminum's density is only one-third of steel, 2.7 g/cm^3, so aluminum is often referred to as a light metal. Pure aluminum is weak, its tensile strength is around 90 MPa. Aluminum's strength can be increased dramatically by alloying aluminum with one or more elements such as silicon and magnesium. Processing the aluminum also makes it stronger, for example, cold rolling can double the strength of pure aluminum. Low density combined with alloying or processing gives aluminum a high strength-to-weight ratio. It's also worth noting that aluminum's strength does not change at lower temperatures and aluminum does not have a ductile to brittle transition temperature that most steels have. Therefore, aluminum is often used for cryogenic applications.

In addition to a high strength-to-weight ratio and nonferromagnetic property, aluminum also has a high resistance to corrosion in many conditions due to its self-forming microscopic surface layer of aluminum oxide. The oxide layer on a new aluminum surface is about 2.5 nm and over time it can grow thicker than 10 nm. This oxide layer is self-renewing, i.e. scratches and other mechanical damages are quickly coated by the new layer. The layer is stable when the surrounding pH is between 4 and 8.5. Aluminum is corrosion resistant to many acids, whereas alkalis are corrosive to aluminum because they destroy the oxide layer. Due to this oxide layer aluminum does not normally require any finishing.[22)]

Aluminum is soft and therefore easy to forge and form. Aluminum can be cut, extruded, turned, glued, and welded (if the oxide layer is considered in welding.) Aluminum's heat expansion is significant, especially when compared with steel. Aluminum is also an eco-friendly material. 100% of aluminum can be recycled and 75% is already recycled. Producing an aluminum ingot from recycled aluminum requires only 5% of the energy that is consumed when the aluminum ingot is produced from primary aluminum.

[22)] *Davis J.R. 1999. Corrosion of Aluminum and Aluminum Alloys (#06787G). ASM International ®.*

STAINLESS STEEL

The difference between steel and stainless steel is the chromium content. Stainless steel contains a minimum of 10.5% chromium, which reacts with surrounding oxygen to form a thin oxide layer on the top of steel. This rapid reaction is referred to as passivation. The oxide layer is self-renewing, i.e. scratches and other mechanical damages are quickly coated by the new layer as long as new chromium is available. On the other hand, if the steel does not contain enough chromium near the surface, a new chromium oxide layer cannot be formed, and stainless steel will rust. In that case, stainless steel is vulnerable to several types of corrosion, such as general corrosion, galvanic corrosion, and pitting corrosion.

Stainless steels are often divided into four types: austenitic, ferritic, martensitic, and duplex. The most commonly used type in industry is austenitic due to its strong protection against rust.[23] Ferritic stainless steel also contains enough chromium to create a protective layer, although it is soft and depending on exact contents, may be challenging to weld. Martensitic stainless steel contains only a minimum amount of chromium and hence its corrosion protection is the weakest type of stainless steel and can often be very challenging to weld. The content, and hence also properties, of high alloyed duplex (ferritic-austenitic) stainless steel varies. Very often they are magnetic, strong and their corrosion resistance is good.

Another classification of stainless steel is the molybdenum content (Mo), because molybdenum as an alloy increases the corrosion protection of the steel, and is especially resistant to pitting attacks caused by chloride. This steel alloyed with molybdenum is referred to as acid-proof stainless steel (HST) and is widely used in industrial activities that handle acids and salts. Molybdenum-free stainless steel is known as RST. An example of the difference between HST and RST is that at room temperature stainless steel 1.4301/X5CrNi18-10/AISI304 (RST) is only resistant to 3% acid, while 1.4404/X2CrNiMo17-12-2/AISI316 (HST) is resistant up to 20%. Of course, both HST and RST corrodes in certain environments. Both 304 (RST) and 316 (HST) are mentioned in IEC-EN 61537 as reference materials. (See: Table 4) In addition to enhanced resistance against pitting corrosion, molybdenum increases steel's hardenability and strength.

ZINC COATING

Steel will corrode in almost any environment if it is unprotected. Zinc coating is a widely used method to protect steel by providing a physical barrier, as well as cathodic protection for the underlying steel. Zinc coating creates a metallic barrier that prevents moisture from contacting the steel. The metallic barrier formed prevents corrosion as corrosion is not possible without direct moisture contact. Physically protected steel won't corrode but zinc will due to its slower electrode potential in the presence of moisture and atmospheric pollutants. Therefore, the lifetime of the physical barrier is proportional to the zinc coating thickness. The lifetime of the physical barrier can be extended by painting the zinc coating, i.e. creating a duplex protection. In addition to physical protection zinc coating protects steel galvanically (cathodic protection). This means that zinc and steel create a galvanic pair when moisture is present and zinc sacrifices itself in the vicinity of bare steel, such as a cut edge or surface scratch. As long as enough zinc is available the steel should not corrode.

Table 3 presents zinc loss per year under particular corrosion categories. As shown, zinc losses increase when the corrosion category rises but the amount of zinc lost is only a fraction of the steel, e.g. in the corrosivity category C4 steel loss is at least 50 µm/year whereas zinc loss is only 2 µm/year. It is straightforward to calculate a zinc coating's lifetime when the corrosion category (environment) is known. For example, in the corrosivity category C4, zinc coating thickness 50 to 100 µm is required for a 25-year lifetime. 50 µm is a rather thick zinc coating and bath hot-dip galvanizing is required to reach that thickness. Other coating methods are pre-galvanizing, electro-galvanizing, and bolt and nut galvanizing. In Finland, the rule of thumb is that zinc loss in a rural environment is 0.5 µm/year and in an urban environment 1 µm/year. In the wood processing industry, zinc losses are outside 0.5-1.5 µm/year, if zinc coating is not encumbered with base or acid. This means that the harshest environment in Finland would be C3 if the classification of the standard ISO 12944 (Table 3) is followed.[24] The zinc losses will quicken notably when the environment's pH goes above 13 (alkaline) or sinks below 6 (acid). However, an environment's pH alone doesn't provide a reliable estimation of the pace of zinc losses as carbonate contents and temperature also have an impact on zinc losses.

Hot-dip galvanization

Hot-dip galvanizing, or bath hot-dip galvanizing, refers to coatings formed by immersing steel into molten zinc. This can be done in the steelworks by galvanizing steel (typically sheet, wire or tubes) automatically as a part of process. This method is called as a pre-galvanization and it will be introduced in the next chapter. Hot-dip galvanization is often done for end products by immersing them into molten zinc, called as a bath hot-dip galvanizing (HDG). This process enables thicker zinc coatings, the minimum thickness of the zinc coating in 1 mm thick steel is 35 µm in accordance with EN ISO 1461. Hot-dip galvanized Meka products have zinc coating of 45 µm or more. Another crucial benefit of bath galvanization is its ability to provide complete coverage of the end product. Internal surfaces, cut edges, welding, everything will be covered by zinc and therefore lifetime of the product will extend.

The bath hot-dip galvanizing process is simple: at first, the surface preparation occurs (degreasing, pickling, fluxing), then the galvanizing itself, and inspection as the final step.[25] Figure 20 illustrates

[23] Reliance Foundry. Does Stainless Steel Rust?
[24] Suomen Kuumasinkitsijät R.Y. 2007. Kuumasinkityksen toimintaketju, yleisohje.

Galvanizing Process

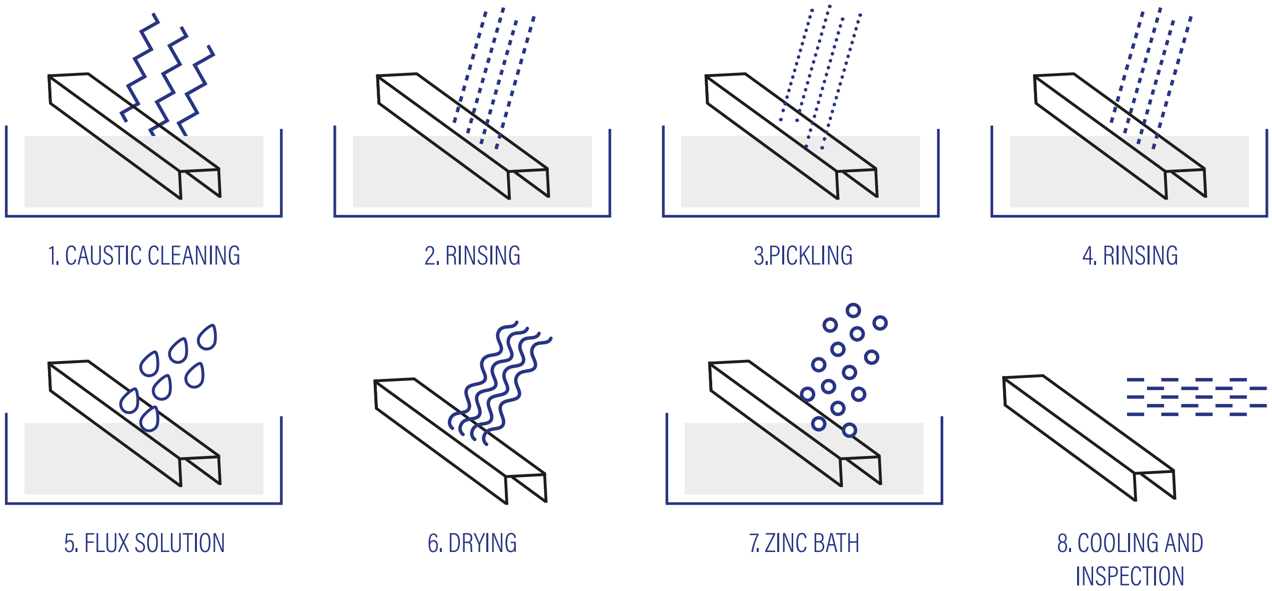


FIGURE 20
The bath hot-dip galvanizing process.

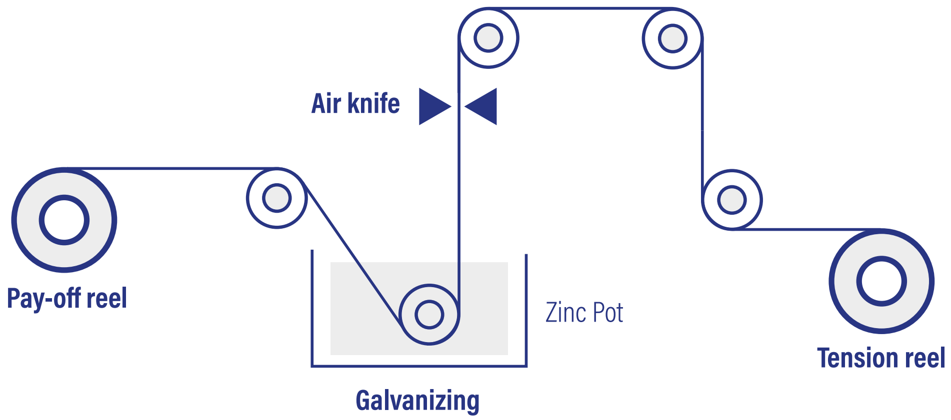


FIGURE 21
Continuous hot-dip galvanization line to produce galvanized sheets.

the process. The surface preparation is the most important step in hot-dip galvanization. In most cases, a coating fails before the end of its expected lifetime due to incorrect or inadequate surface preparation. Galvanizing time defines the zinc coating thickness if the base material is correct. Normally bath galvanization can produce a 50 – 200 µm thick layer.

Pre-galvanization

Pre-galvanization (Sendzimir) is done as part of the steel manufacturing process at the steelworks, i.e. it is not suitable for end products. The process itself is very similar to bath galvanizing, though it is done continuously. The only difference is the jet process by air knife that is used to set the desired coating thickness and improve the surface quality. Other steps from the beginning are cleaning, re-crystallization or heating up, temperature cooling of the molten metal, hot-dip galvanization in the coating liquid bath, jet processing, cooling, and chemical after-treatment. (See: Figure 21) Pre-galvanization provides a better appearance, but often a thinner zinc coating than bath hot-dip galvanizing does. For example, Meka Pro uses Z275 coating which guarantees the coating thickness of (typical) 20 µm. Table 7 presents the differences between bath and pre-galvanization. The basic specification for galvanized coatings on iron and steel articles is defined by the standards EN 10346.

Electro-galvanization

Electro-galvanization or zinc plating is a process where a thin coating of zinc is electrodeposited onto the surface of the steel. The process includes the following steps: preparing and cleaning surfaces, preparing the plating solution, rack or barrel plating, introducing the electrical current, and post-treatment.[26] Often the zinc plated coatings are passivated to slow down zinc oxidation. Passivation protects zinc from white rust and zinc protects the base material from red rust. The corrosion protection will improve even more if the post-dip (sealer) is completed after passivation. Normally the zinc plating coating thickness is around 10 µm, see more in EN ISO 2081.

Centrifugal hot-dip galvanization

Small products (approximately 10 – 500 mm), can be galvanized by centrifugal hot-dip galvanization, also known as bolt and nut galvanizing. This method is similar to bath galvanizing, i.e. products must be prepared (degreasing, pickling, fluxing) for galvanizing, which is done so that small products can be placed inside perforated baskets during the hot-dip process. Once the baskets are dipped, they are transported into the centrifuge to remove excess coating. The centrifuge partially removes the top zinc layer and hence provides a matte appearance and dimensional accuracy of the products.

Zinc flake coating

An optional method to protect small products (often fasteners), as well as bigger products (e.g. springs), from corrosion, is the zinc flake coating method following ISO 10683 or EN 13858. In this method, protected products are submerged in an inorganic liquid carrier filled with small zinc and aluminum flakes, which is then followed

Feature	Bath hot-dip galvanization	Pre-galvanization
Coating thickness	Thick coating with minimum average requirements of 45-85 µm within EN ISO 1461	The coating thickness varies, typically between 7 and 42 µm within EN 10346
Coating continuity	Continuous coating over the end product	Uncoated areas at cut edges
Coating bond	Strong metallurgical bond with the base metal	Strong metallurgical bond with the base metal
Abrasion resistance	Thicker layer of hard zinc-iron alloy gives a high resistance to abrasion	Thin alloy layer with reduced resistance to abrasion
Coating formability	Forming after galvanizing may damage coating	Thin coating may normally be formed without damage
Sacrificial protection	Offers the highest level of sacrificial protection	Thinner coating means reduced sacrificial protection which may lead to rust staining from cut edges on sheet
Coating appearance	Variable, typically bright	Typically a uniform bright finish
Consideration of design for galvanizing required	Yes	Yes

TABLE 7

Bath hot-dip galvanizing vs pre-galvanizing acc. to Galco.[27]

[25] *Galvanize It! Online seminar. Hot-Dip Galvanizing (HDG) Process.*
[26] *Surface Treatment Experts. The zinc plating process.*
[27] *Galco. Batch Galvanized vs Pregalvanized Products.*

FIGURE 22

Electro-galvanized (left) and zinc flake coated (right) parts after a 550-hour salt spray test.

by spinning to remove any excess liquid. The solid zinc-aluminum layer is finished by baking products in an oven. The result is a matte grey surface, which provides high corrosion resistance although the coating thickness is only 5-12 µm. Figure 22 presents the difference between electro-galvanized and zinc flake coated products after a 550-hour salt spray test. The corrosion protection of zinc flake coating is based on three methods: barrier protection, galvanic protection, and passivation. Benefits of zinc flake coatings include the possibility to protect complex shapes, avoidance of hydrogen embrittlement due to non-electrolytic process, and electrical conductivity. In industry, zinc flake coating is better known as Geomet.

Chemistry

The chemistry of carbon steel influences the surface finish of galvanized carbon steel. The particularly reactive elements in steel, silicon (Si), and phosphorus (P) may affect hot-dip galvanizing in terms of uniformity, color, and relative smoothness. Silicon content is used as a limit between aluminum killed steels (Si <0.03%) and silicon killed steels (Si >0.03%). The term "killed steels" arises from steel production's degassing and de-oxidizing, where either silicon or aluminum is added during manufacturing to remove oxygen, resulting in the name "killed steel". If neither aluminum nor silicon is added, steel is referred to as a "rimming steel". Rimming and aluminum killed steels are suitable for hot-dip galvanizing if the silicon content is below 0.03 weight percent. Silicon killed steels with a silicon content above 0.14 weight percent can also be galvanized. If a thicker zinc coating is the target, then a higher silicon content is recommended. The optimal silicon content for thicker zinc coatings through hot-dip galvanizing is the limited mid-silicon zone, which is 0.15-0.2 weight percent. At this level of silicon content the surface finish will be thick enough, smooth, and bright (though grey and dark areas are possible with thick steels). Increased silicon content causes a thicker coating and more color variation. For thick zinc coatings, it is suggested to use steel with a silicon content larger than 0.22% (Si > 0.22%), in which case the resulting coating may be grey and dark. It's also worth noting that thick zinc coating is brittle and may flake off during handling. The phosphorous content of the steel influences the reactivity too, especially in cold rolled steel. Other alloying elements in the steel have no clear influence on the coating.[28)]

Steel is called as a "Sandelin steel" if the cumulative silicon and phosphorous content is in the range 0.03 – 0.14 % (0.03% ≤ Si + P ≤ 0.14%). "Sandelin steel" should not be hot-dip galvanized or at least special types of galvanizing bath should be used, because a standard zinc bath often causes strong reactions between "Sandelin steel" and zinc. The resultant coating is thick, irregular, and poorly adhered. Therefore, if the aesthetic value is an aspect of the selection criterion, the cumulative silicon and phosphorous content should be less than 0.03% (Si + P ≤ 0.03%), which is referred to as a sub-silicon zone. Previous alloying is adequate in most cases. If the more accurate alloying instructions are needed for extremely high-level appearance, then cold-rolled steels

28) Hot Dip Galvanizers Association Southern Africa. 2015. Hot Dip Galvanized Information Sheet No.14: Hot Dip Galvanized Surface Finishes caused primarily due to the effect of Silicon and Phosphorous in Steel. Nordic Galvanizers. Steels suitable for galvanizing.

	Cold rolled steel	Hot rolled steel
Si + P < 0.03	Acceptable surface finish in most cases. Shiny coating. Thickness according to standard. Better, high-quality appearance, with content: Si<0.03 and Si+2.5P<0.04.	Acceptable surface finish in most cases. Shiny coating. Thickness according to standard. Better, high-quality appearance, with content: Si<0.02 and Si+2.5P<0.09.
0.03 < Si + P ≤ 0.014	Not suitable	Not suitable
0.15 ≤ Si ≤ 0.21	Thicker coating than in standard. Internal oxidation may change reactivity.	Thicker coating than in standard.
0.22 ≤ Si ≤ 0.28	Significant thicker coating than in standard. Grey appearance.	Significant thicker coating than in standard. Grey appearance.
0.29 ≤ Si ≤ 0.35	Thick coating that may be brittle. Grey appearance.	Thick coating that may be brittle. Grey appearance.

TABLE 8

Impact of silicon (Si) and phosphorous (P) content on galvanized cold- and hot-rolled steels.[29]

should meet the ranges: Si < 0.03% and Si + 2.5 x P < 0.04%. Hot-rolled steel should meet the ranges: Si < 0.02% and Si + 2.5 x P < 0.09%. The impact of possible heat treatments and their impact on galvanizing should not be ignored. For example, cold-rolled steel with a silicon content in the range of 0.15-0.21% may turn to the "Sandelin zone" due to annealing. Table 8 presents the influence of silicon and phosphorous content when galvanizing cold-rolled and hot-rolled steel.

Appearance

As claimed by the standard ISO 1461, the main purpose of the galvanized coating is to protect the covered material against corrosion. Aesthetics and decorative features should only be secondary considerations. The standard ISO 1461 states that the acceptance inspection should be examined by normal or corrected vision from a distance of not less than 1 m. The significant surfaces of all hot-dip galvanized articles should be free from nodules, blisters, roughness, sharp points, and uncoated areas. Therefore, the occurrence of darker and lighter areas, e.g. cellular pattern, dark grey areas, or some surface unevenness should not be a cause for rejection. The development of wet storage staining, primarily basic zinc oxide (formed during storage in humid conditions after hot-dip galvanizing), is not a cause for rejection, so long as the coating thickness remains above the specified minimum value. If the appearance and aesthetics are also important the customer and supplier must agree upon the standard of finish. In that case, it should be noted that roughness and smoothness are relative terms and in practice, it is challenging to establish both the appearance and finish whilst covering all requirements.

PAINTING

Paint is the most commonly used material to protect steel and enhance its appearance. The purpose of corrosion protection painting is to protect the metal substrate against atmospheric corrosivity, either by providing a physical barrier or by reducing the formation of local galvanic pairs. If the paint contains a sufficient quantity of zinc, it can also provide cathodic protection. Normally paints are composed of binders (or resin), pigments, fillers, solvents, and additives. Binders provide the basis of a continuous paint film, sealing or otherwise protecting the surface to which the paint is applied. Binders determine the characteristics and performance of the coating, such as adhesion, strength, and durability. Pigment provides the color and other visual effects. Whilst pigment is used for aesthetic reasons, though it may also include anti-corrosive properties. Filler increases the paint film density and influences many other characteristics of the coating, such as the level of gloss provided. A solvent is used to dissolve the solid resins and polymers, and to reduce the viscosity of the binder, i.e. solvent enables the paint to be applied to surfaces. Additives are minor components, wide in variety and effect, e.g. catalysts, driers, and flow agents. The main methods of applying paint are spreading, spraying, flow coating, or electrodeposition. Brush and roller are well-known examples of spreading, whereas air-fed spray and airless spray are spraying methods. Dipping belongs to the category of flow coating.

[29] Nordic Galvanizers. Steels suitable for galvanizing.

Paint and the method of applying paint are chosen according to application and its requirements. Each paint technology has its own standards and test methods. Painted cable trays are normally made of pre-galvanized and painted steel plates. Paint applied over metal coatings is referred to as a duplex coating system and it is completed in the steelworks as a continuous coil coating process. The paint film is created using a polyester binder, which provides a resilient and durable coating. When a polyester binder is blended with ceramic pigments, it offers outstanding weathering properties.[30)] Polyester binders have also enjoyed widespread use due to the broad spectrum of colors available and their suitability to many substrates.

ZINC-MAGNESIUM COATINGS (ZM)

The duration of protection against corrosion provided by a zinc coating is directly relative to the thickness of the zinc coating. The thicker the zinc coating on the steel sheet, the longer the protection against corrosion. As a thicker coating demands more raw material and energy during manufacturing, it is expensive and can result in the waste of natural resources. A similar or even greater duration of corrosion protection can be reached by alloying other elements to the zinc. For example, corrosion protection improves notably if both magnesium and aluminum are alloyed with zinc. Several pieces of research have shown that zinc-magnesium coated steel has a greater corrosion resistance when tested than conventional zinc-coated steel of similar coating thickness. Improvements of 24x longevity have been reported despite the zin-magnesium coating being lighter than galvanization.[31)]

The improved corrosivity protection of zinc-magnesium coating is based on the combination of a physical barrier effect, cathodic protection, slower zinc dissolution, and inhibition layers formed by corrosion products. Just like traditional zinc coating, zinc-magnesium coating provides a cathodic protection against corrosion. In addition to zinc sacrifice, zinc-magnesium coating provides a zinc-based film with magnesium. This thin film slows down the reaction between oxygen and the steel sheet and creates stronger corrosion protection around scratches and cut edges. The nature of the zinc-based film with magnesium depends on the corrosion environment, the harsher environment, the stronger film.

Normally zinc-magnesium coatings have used an alloy containing up to 8% magnesium and aluminum in addition to the zinc content. For example, ArcelorMittal's zinc-magnesium coating (brand name Magnelis) has a chemical composition of zinc with 3.5% aluminum and 3% magnesium, whereas Tata Steel's zinc-magnesium coating (brand name MagiZinc) has a different chemical composition.

The zinc-magnesium coating is also eco-friendly as it reduces the zinc runoff to the soil, and saves resources and energy in production. The runoff rate describes the material's dissolution from its surface into its surroundings ($g/m^2/a$). For example, the amount of zinc washed from the coating by falling rainwater. The zinc runoff rate of a zinc-magnesium coating is reduced due to the precipitation of magnesium hydroxide at cathodic areas reducing the oxygen reduction rate and resulting in increased formation of protective aluminum oxide.[32)] Natural resource and energy savings in production are also possible because of zinc-magnesium coating's slower coefficient of friction. Zinc-magnesium coated steel is easier to form than traditional zinc-coated steel. Hence, it may be possible to form zinc-magnesium coated steel sheets without emulsion, which has a clear impact on production efficiency and cleanliness.

ZINC-ALUMINUM COATINGS (ZA)

Zinc-aluminum coating, also known as Galfan, was developed around 1980 and nowadays is incorporated into many international standards, such as EN 10346 and JIS 3317. Galfan contains 95% zinc and 5% aluminum. This alloy forms the thin film of corrosion products on the zinc alloy surface causing the corrosion rate of the zinc-aluminum coating to slow down over time, due to aluminium-containing corrosion products, which enrich the surface. As zinc-aluminum coating contains zinc, it has the sacrificial protection of zinc in addition to the barrier protection. Therefore Galfan also has the ability to protect the steel on cut-edges and around scratches. The zinc-aluminum coating's resistance to corrosion is tested to be at least twice as resistant as regular zinc coating.

Galfan's microstructure is lamellar, which makes it malleable and ductile. Therefore, Galfan coating doesn't break during forming and it has good formability and paintability. An additional benefit of zinc-aluminum coating in forming is its surface's lower coefficient of friction, which makes it possible to use less emulsion in production.

MECHANICAL STRENGTH OF THE CABLE MANAGEMENT SYSTEM

The standard IEC 61537 states that cable management systems must be designed and constructed so that in normal use when installed according to instructions, they ensure reliable support to the cables contained therein. Cable management systems should not impose any unreasonable hazard to the user or cables. Reliability of design, safety, and adequate mechanical strength must be checked by carrying tests specified in IEC 61537. Then the manufacturer or a responsible vendor can provide a safe working load (SWL) of the cable management system or its components. The safe working load (SWL) is the maximum load that can be applied to the cable management system, or its components safely within normal use. For the declared system, the manufacturer or responsible vendor shall declare the SWL to be tested:

- in N/m for each type of cable tray length or cable ladder length at specified distances,

30) Haddock R. 2002. Metal roofing from A (Aluminum) to Z (Zinc) – Part III, Paint finishes for metal. Metalmag.
31) Hosking N.C., Ström M.A., Shipway P.H. & C.D. Rudd. 2007. Corrosion resistance of zinc–magnesium coated steel. Corrosion Science 49, 3669–3695.
32) Wallinder O. & Leygraf C. 2017. A Critical Review on Corrosion and Runoff from Zinc and Zinc-Based Alloys in Atmospheric Environments. Corrosion Vol. 73 No. 9, 1060-1077.

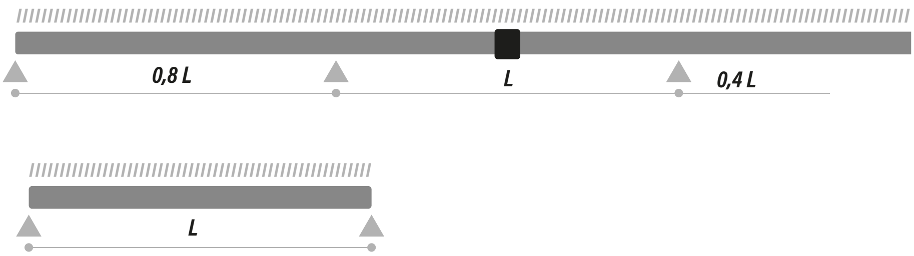


FIGURE 23

Multiple span test (upper figure) and single span test (lower figure) arrangements to define SWL in accordance with IEC 61537.

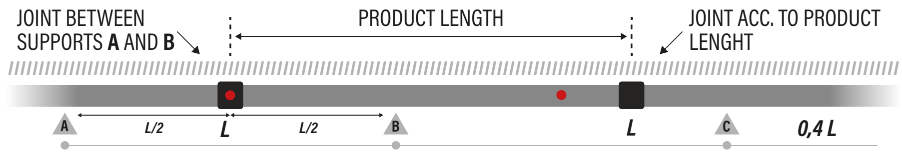
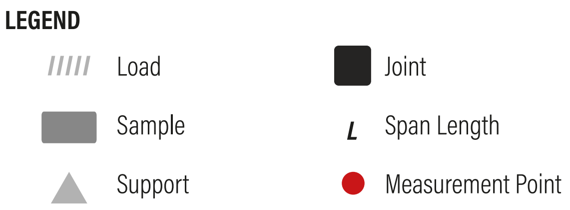


FIGURE 24

Test type 1's test arrangement to define corresponding SWL and deflection.



preferably in spans of 0.5 m increments, between the support devices,

- in N/m for each type of fitting which is not directly supported by a support device, or
- in N or N/m for each type of support device.

The test procedure for safe working load (SWL) is clearly described in standard IEC 61537. The standard demands the use of a uniformly distributed load over the length and width of the sample so that the load is ensured to be uniformly distributed in the case of extreme deformation of the sample. The measurement itself goes as follows:

1. Increase the load up to pre-load, which is 10% of the SWL.
2. Settlement of the sample by maintaining the pre-load for five minutes.
3. Removing the load and resetting the measuring equipment.
4. Increasing the load either by increments or continuously up to the SWL.
5. Maintain the SWL and measure deflection every 5 minutes until the difference between two consecutive sets of readings is less than 2% regarding the first set of the two consecutive sets of readings. The first set of readings measured at this point are the deflection measured at the SWL.
6. Increase the load on the sample up to 1.7 times the SWL.
7. Maintain 1.7 times the SWL for 5 minutes. This stage should be fulfilled as in SWL, item 5.

The sample, its joints, and internal fixing devices should show no damage or cracks visible to normal view or corrected vision without magnification when subjected to the safe working load (SWL). This means that stresses in any component cannot exceed the yield limit of the concerned component. The mid-span deflection of each span at the safe working load (SWL) must not exceed 1/100th of span. When loaded by 1.7 times the SWL, buckling and deformation of the sample are permissible but the sample should sustain the load without collapsing. In other words, the stresses of the components must be less than the ultimate tensile strength in all components, whereas the yield strength limit can be exceeded.

Meka Pro has the certified and calibrated test device to perform safe working load (SWL) tests in accordance with IEC 61537. The test device is calibrated and the test process certified by an independent third-party to ensure the reliability of the test device and test procedure's compliance with the standard IEC 61537.

In accordance with IEC 61537 the safe working load (SWL) can be measured for multiple span systems or a single span installation. (See: Figure 23) Furthermore, the multiple span test can be executed in accordance with four different test types, which are presented in the following chapters.

Test type 1 allows the customer to place joints on all of the installations, i.e. joints can occur anywhere on an installation. End span limitations exists neither. In practice this means that the manufacturer or a responsible vendor must place the joint in the middle of end span in verification tests. The manufacturer or responsible vendor shall measure the deflection therein in accordance with IEC 61537. (See: Figure 24) This is the most challenging case and it causes maximum deflection. On the other hand, it makes installation on the construction site easy because there is no need to focus on the location of the joints, the joints can be placed on all installations and the measured results remain valid.

Test type 2 does not allow a joint in the end span and the manufacturer or responsible vendor can declare the end span length X. In practice, this means that the manufacturer or responsible vendor must place the joint in the middle of the intermediate span in verification tests. The manufacturer or responsible vendor must measure the deflection therein in accordance with IEC 61537. (See: Figure 25) This is a challenging case and it causes maximum deflection in the intermediate span. Joints are not allowed to be placed in the end span, and the length of the end span may need to be adjusted in accordance with the manufacturer's or responsible vendor's declaration. Otherwise, joints can be placed on all sections of the installation.

Test type 3 allows the customer to place the joint only as declared by the manufacturer or responsible vendor. The location of the joint is relative to the end support on all installations. (See: Figure 26) The manufacturer or responsible vendor can also declare the end span length X. In practice, this means that the manufacturer or responsible vendor can place the joint freely in verification tests in accordance with IEC 61537.

Test type 4 is used if the weakness of the system is localized. The localized weakness is positioned over the support, as shown in Figure 27. When possible, joints should be placed by modifying test type 1 or 2 by moving the joint by up to ±10% of L from its specified position. Then the SWL and deflection are measured accordingly so that customers will get valid information for their system.

Figure 28 illustrates the safe working load test arrangement for a single span. If the manufacturer or responsible vendor does not declare the joint's place then it must be placed at the mid-span position to reach the maximum deflection and hence the worst-case result for customers. The joint is not needed, when the cable tray or ladder is longer than the span.

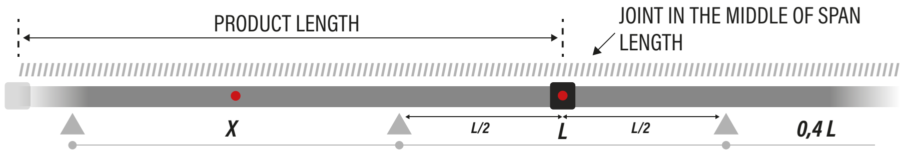


FIGURE 25

Test type 2's test arrangement to define corresponding SWL and deflection.

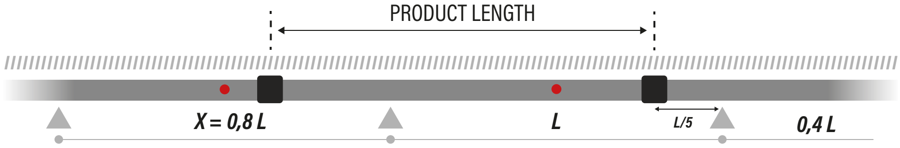


FIGURE 26

Test type 3's test arrangement to define corresponding SWL and deflection.

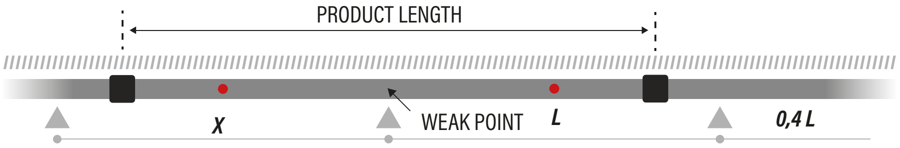
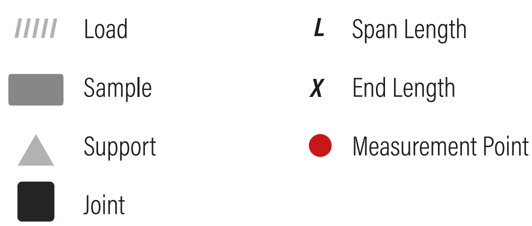


FIGURE 27

Test type 4's test arrangement to define corresponding SWL and deflection.

LEGEND



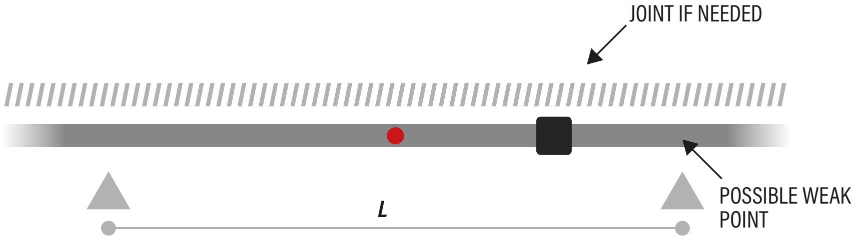


FIGURE 28
Single span test arrangement to define the corresponding SWL and deflection.

FIGURE 29
A simply supported beam on the left and fixed supported beam on the right. Both arrangements are well-known and presented in literature.

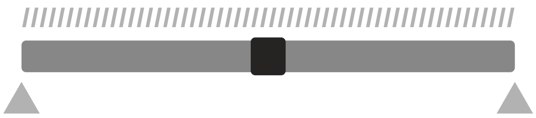
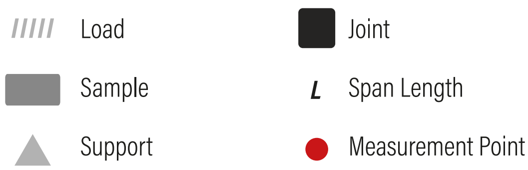


FIGURE 30
A simple supported beam with a mid-span joint, which is complex to calculate.

LEGEND



[33] *StructX. Continuous Beam - Four Span with UDL. Janicki D. Continuous Beam Bending Tables. YourSpreadsheet™*

Structurally, a single span system corresponds with a single beam, which is used as a fundamental way to teach engineers the basics of static loading. Figure 29 presents two well-known single beam arrangements: a simply supported beam on the left and a fixed beam on the right. Both of these arrangements are well-known and comprehensively presented in the literature. Therefore, they can be efficiently used to calculate the deflection of a single beam when the cross-section of the beam and loading are known. Many cross-sections and their parameters are presented in the literature. Many loads, such as the uniformly distributed load as demanded in IEC 61537, and their impact on deflection are also given in the literature. Thus, in addition to deflection, the stress of the beam, and hence the safe working load, can also be calculated for a single beam with certain accuracy.

Unfortunately, single beam arrangements provide only a trivial reflection to reality, even in cable management systems. Fixed boundary conditions are rare in the assemblies of the cable management systems and pin supports (simple support) are simplifications from reality. The third deviation is the system itself. Tangible cable management systems quite often incorporate more than one beam and two supports. At least one joint is needed and at which point the deflection cannot be calculated easily because the properties of the joint have a strong influence on the results. For example, the case presented in Figure 30 does not correspond with the case presented in Figure 29. In addition to the joint, a tangible system normally incorporates several supports. Several support systems can be visualized with continuous beams. (See: Figure 31 A continuous beam is a beam that is loaded and has more than two supports along its length. Once again, the continuous beam is an over-simplified model of reality because it ignores joints. However, the theory of continuous beams visualizes the impact of the counterbalance of the adjacent beams. The maximum deflection and the maximum bending moment exists between the first and the second supports, or the final and previously consecutive supports.

This is caused by the missing counter support on the other side.[33] Due to larger deflection and the bending moment in the end span, its maximum length is normally declared by the manufacturer or a responsible vendor. As shown, several factors influence the deflection and safe working load, hence both SWL and deflection should be measured in accordance with IEC 61537 instead of via calculation.

Figure 32 presents a cantilever beam and a cantilever beam with a uniformly distributed load, which can be used as a simplified calculation model of wall supports. Both cases are widely presented in the literature, so the basic calculation is rather easy to execute. However, the sources of inaccuracies presented above are valid with cantilever beams too. Therefore, tests in accordance with IEC 61537 are recommended instead of calculations to provide accurate results.

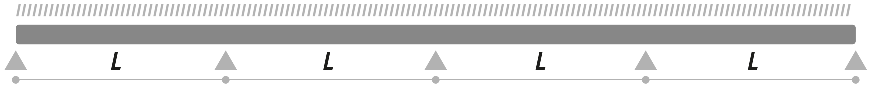


FIGURE 31
Continuous beam system with five supports.

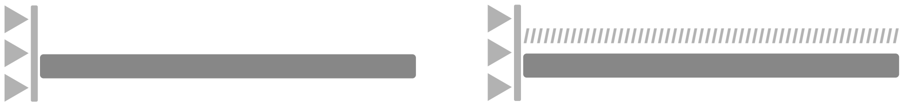
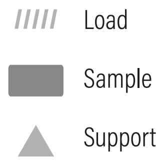


FIGURE 32
Cantilever beam.

LEGEND



SUMMARY

The cable management system may look like a simple steel construction, which only needs to be installed on the wall or ceiling. But many standards, regulations, and instructions must be complied with in design, sourcing, manufacturing, and installation, so that the cable management system meets all requirements, is safe to use, and fits its purpose in all environments.

Designers and operators can follow the following simplified checklist to maximize the cable management system's lifespan and safety:

1. Determine the atmospheric-corrosivity category (C1-CX) wherein the cable management system will be installed. The appropriate material and surface treatment for the cable management system is chosen in accordance with atmospheric-corrosivity category. Appropriate surface treatments for the various ratings include:

- Electro-galvanising (EG), pre-galvanised steel (PG) and painted pre-galvanised products (M) are suited for category C1 (heated interior spaces) and C2 (unheated buildings, such as warehouses, and rural buildings).
- Hot-dip-galvanised products (HDG) and zinc alloy coated products (XPG) are suited for category C3 (humid interiors as well as city and urban environment) and C4 (chemical factories as well as industrial and coastal areas with moderate salinity).
- Acid-proof steel (HST) is suited for category C5 (polluted and constantly humid interiors as well as humid and corrosive industry and coastal areas) and CX (extremely humid and corrosive industry and offshore areas as well as subtropical and tropical climates).

2. Determine the cable load (kg/m) and span (m). Cable load influences the definition of the span, and alternatively vice versa. Shorter spans enable to carry heavier loads and longer spans may limit the carried load. Product-specific load details, including maximum allowed load, must be confirmed from the manufacturer or responsible vendor. Meka Pro provides product-specific load capacities in product catalogs, datasheets and www.meka.eu.

3. Review fire resistance requirements of the construction object. Product width, the span, maximum load and the installation method are limited for fire-resistant installation. Therefore, approved installation methods are set for each product family separately, and they must be confirmed from the manufacturer or responsible vendor. Fire-resistant installation of MEKA® products is carried out with separate instructions. The instructions can be downloaded at www.meka.eu.

A responsible cable management system manufacturer's every function must consider many issues during their daily work to ensure reliable, safe and sustainable cable management systems.

Every decision may have a huge impact on the quality and functionality of the end product. In other words, even a small wrong choice at any point of the chain may deface the end product and hence influence the schedule of a huge construction site. On the other hand, small right choices by experienced people may provide huge benefits on the construction site and save money and resources during the cable management system's lifetime. All choices must be based on knowledge and to experience, and as shown in this book, knowledge is needed in many fields.

Although this book presents fundamentally many topics related to cable management systems, it does not cover all. Each topic could be extended significantly if all of the information would be provided. So, besides this book, plenty of valuable information and knowledge of cable management systems is still available and Meka Pro will be glad to share that information with customers.

Meka Pro is listening customers every day to provide even better cable management systems. Therefore, do not hesitate to contact us. We will be happy to help you find the right solutions for the right sites and to make sure that your project is completed on schedule and cost-effectively.

TERMINOLOGY

ALUMINUM
The third most abundant element and the most abundant metal in the earth's crust. Aluminum is one of the lightest metals, is not vulnerable to corrosion, and does not have a ductile-brittle transition making it suitable for cryogenic applications.

BATH HOT-DIP GALVANIZING (HDG)
Zinc coating process where the end product or a formed part is dipped in a zinc bath. Then the entire end product and possible welding, cutting surface, etc. are covered by zinc, and therefore protected from corrosion.

BIM
Building Information Modeling is a collaborative process to ensure efficient information handling during the building lifetime, from the design to the management of buildings, with various tools, by multiple stakeholders. Building information models are intelligent objects comprised of geometry and stored data, which visualize the building and enables versatile analysis.

BONDING
Same as potential equalization, non-current-carrying metal parts are connected so that their electrical potentials remain equal. Equal potential prevents current flow and sparking between components

CABLE LADDER LENGTH
Cable ladder system's component used for cable support, consisting of supporting side members, which are fixed to each other by rungs.

CABLE TRAY LENGTH
Cable tray system's component used for cable support, consisting of a base with integrated side members or a base connected to side members. Cable ladder system: Assembly of cable supports consisting of cable ladder lengths and other system components, such as joints, mounting parts, and supports.

CABLE RUNWAY
Assembly consisting of a cable ladder or tray lengths and fittings only.

CABLE TRAY SYSTEM
Assembly of cable supports consisting of cable tray lengths and other system components, such as joints, mounting parts, and supports.

CENTRIFUGAL GALVANIZATION
Component is centrifuged after removal from the galvanizing bath. Centrifugation combines mechanical precision and protective qualities of zinc coating on small products, therefore the method is also referred to as bolt and nut galvanization.

COATING THICKNESS
Total thickness of zinc, paint, or zinc alloys, or zinc-paint alloys on iron and steel products.

CONDENSATION
Process where water vapor becomes liquid. Condensation happens if the air is cooled to its dew point, or if the air is so saturated with water vapor that it can't hold any water more.

CORROSION
Degradation of material through contact with its environment. Though corrosion happens in non-metallic materials too, normally it is understood as wastage of metal by chemical and/or electrochemical reaction with their environment.

CORROSIVITY CATEGORIES
Standards ISO 12944 and ISO 9223 define corrosivity categories for atmospheric environments by the first-year corrosion rate of standard specimens, and standard IEC 61537 classifies materials and finishes for resistance against corrosion.

DAMAGE
Physical harm on the cable management system or its components that impairs the usage of the system or component, e.g. broken rung, missing welding, etc.

DEFLECTION
The movement or bending of the cable management system's components caused by the component's own weight or external load.

DYNAMIC LOAD
Load that may change in magnitude or position with time, i.e. any non-static load, like load caused by vibration or wind. Dynamic load and vibration may be caused by short-circuit current, which generates an abnormally high current, temperature, and mechanical force.

EARTHING
Same as grounding, a process to transfer the immediate discharge of electrical energy

directly to the Earth (zero potential) via the low-resistance wire. The electrical earthing is realized by connecting the non-current-carrying part of the equipment, or the neutral part of the supply system, to the ground (zero potential).

ELECTRO-GALVANIZING
Zinc coating process, where a zinc layer is applied to a steel sheet or wire by electro-deposition. The thickness of the electro-galvanized zinc coating is smooth and minimal. Thin zinc coating is ductile and hence remains intact after severe deformation.

ELECTROMAGNETIC COMPATIBILITY (EMC)
The ability of devices to operate in their electromagnetic environment without impairing their functions and without faults, and vice versa. EMC also ensures that operation does not influence the electromagnetic environment to the extent that the functions of other devices and systems are adversely affected.

ELECTROLYTE
Substances that can conduct electricity. Compulsory factor in the corrosion process.

ELECTROMAGNETIC INTERFERENCE (EMI)
Electromagnetic energy, which affects the operation of an electronic device. Electromagnetic interference can be the result of man-made or natural occurrences, e.g. cellphones, LED, electric storms, solar radiation, etc.

EXTERNAL FIXING DEVICE
Cable management system's device used for fixing a support device to walls, ceilings, or other structural components. External fixing devices are not a part of the system, e.g. anchor bolts.

EXTERNAL INFLUENCE
Presence of water, oil, building materials, corrosive and polluting substances in the cable management system. Also, external mechanical forces such as snow, wind, and other environmental hazards are counted as an external influence.

FITTING
Cable management system's component used to join, change direction, change dimension, or terminate cable ladder or tray lengths

GALFAN
Widely standardized corrosion protection coating that consists of zinc (95%) and aluminum (5%).

GALVANIC CORROSION
Galvanic couple/pair is composed of two or more electrically connected materials with different potentials in electrolytes. The material with the lowest potential (anode) corrodes, whereas the corrosion of the material with the highest potential (cathode) may fully stop.

GALVANIZATION
Process of applying a zinc coating to steel to prevent, or slow down, corrosion. The most common galvanization methods are bath hot-dip galvanizing, continuous galvanizing (in-line galvanizing), electroplating, and zinc-rich painting.

GROUNDING
Same as earthing, a process to transfer the immediate discharge of electrical energy directly to the Earth (zero potential) via a low-resistance wire. The electrical grounding is realized by connecting a non-current-carrying part of the equipment, or the neutral part of the supply system, to the ground (zero potential).

HALOGEN-FREE
Fluorine (F), Chlorine (Cl), Bromine (Br), Iodine (I), or Astatine (At) contents of the material are below the limits declared by standards, such as IEC and DIN. Concerned materials produce a wide range of salts when they react with metal, and some of them are extremely toxic in gaseous form. For example, PVC (Polyvinyl Chloride) is not a halogen-free material.

HOT-DIP GALVANIZING
Zinc coating process where the steel sheet, wire or tube are rolled through the molten zinc prior to further steel working in the steelwork (pre-galvanizing), or the end product or a formed part is dipped in a zinc bath after manufacturing (bath hot-dip galvanizing).

INTERNAL FIXING DEVICE
Device for joining and/or fixing cable management system components to other system components. The internal fixing device is part of the system, but not a system component, e.g. nuts and bolts.

MOUNTING DEVICE
The cable management system's component used to attach or fix other devices to the cable runway.

PH
A decimal logarithmic scale to define how acidic or basic a water-based solution is. The pH of the neutral liquid is 7. If the pH is less than 7, the liquid is acid, and alkaline's pH is more than 7. Note that the difference between two integers is tenfold due to the logarithmic scale. More details in standard ISO 80000-9.

POTENTIAL EQUALIZATION
Same as bonding, non-current-carrying metal parts are connected so that their electrical potentials remain equal. Equal potential prevents current flow and sparking between components.

PRE-GALVANIZING (PG)
Zinc coating process, which is done as a part of steel sheet manufacturing in steelworks, hence also known as a 'mill galvanized' or 'Sendzimir' process. Steel sheets are rolled through the molten zinc prior to further steel working, e.g. cable ladder production. The coating thickness is thinner, but appearance better when compared with hot-dip galvanizing.

REACH (REGISTRATION, EVALUATION, AUTHORIZATION, AND RESTRICTION OF CHEMICALS)
Regulation of the EU since 2004, which requires companies to identify and manage the risks linked to the substances they manufacture and market in the EU. If companies do not provide sufficient instructions and risk management measurements, authorities can restrict the use of the substance.

REVIT
Autodesk's building information modeling (BIM) software, which helps stakeholders to design, simulate, visualize, and collaborate interconnected data within a building information model (BIM).

ROHS (RESTRICTION OF HAZARDOUS SUBSTANCES IN ELECTRICAL AND ELECTRONIC EQUIPMENT)
Directive of the European Parliament and the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

SAFE WORKING LOAD (SWL)
The maximum load that can be applied to a cable management system, or its components, safely in normal use.

SESKO
The National Electrotechnical Standardization Organization representing Finland in the electrotechnical engineering field as the National Committee of the International Electrotechnical Commission (IEC).

SKILLED WORKER
A skilled worker possesses enough technical knowledge and appropriate practical skills to perform his/her work safely without damaging parts or systems.

SPAN
Distance between the centres of two adjacent support devices of the cable management system.

STAINLESS STEEL
A steel alloy with a minimum of 10.5% chromium content by mass and a maximum of 1.2% carbon by mass. In Finland acid-proof steel (HST) is divided from stainless steel (RST) according to molybdenum content, if stainless steel contains molybdenum, it is referred to as acid-proof steel (HST).

STATIC LOAD
Constant load that does not change in magnitude or position with time.

STEEL
The most important utility metal due to its strength. Many mechanical properties of steel can be adjusted with alloying and manufacturing processes; hence thousands of steel grades are available. The only common factor is the carbon content, which must be less than 1.7%, otherwise, it is not steel but instead cast iron.

SUPPORT DEVICE
The cable management system's component that is designed to provide mechanical support and, if necessary, limit movement of the system.

SUSTAINABILITY
Ability to provide human needs by causing a minimum impact on the environment.[31)]

SYSTEM ACCESSORY
Cable management system's component used for a supplementary function such as cable retention and covers.

SYSTEM COMPONENT
Parts or components used within cable management systems, for example, support devices, mounting devices, system accessories, cable tray lengths, cable ladder lengths, cable tray fittings, and cable ladder fittings.

THERMAL EXPANSION
Change in the volume of a material in response to a change in its temperature.

THERMAL EXPANSION COEFFICIENT
Relative material expansion divided by the change in its temperature.

UNCOATED AREA
Areas on the iron or steel articles that are not covered by zinc, paint, or zinc alloys.

UNIFORMLY DISTRIBUTED LOAD (UDL)
Load applied evenly over a given area.

WEEE (WASTE ELECTRICAL & ELECTRONIC EQUIPMENT)
Directive of the European Parliament and the Council on waste electrical and electronic equipment. The directive requires producers of electrical and electronic equipment who sell their products in the EU to operate a recycling program.

WET STORAGE STAIN
Possible layer of white powdery zinc corrosion products composed of zinc hydroxide and zinc oxide, on damp zinc coating. May occur on fresh zinc surfaces stored in a wet environment with limited oxygen.

WHITE RUST
Powdery substance, which can form on the surface of zinc, or zinc-coated materials, when zinc is exposed to hydrogen and oxygen.

ZINC
An element and the fourth most used metal due to its ability to protect steel from corrosion. Pure zinc is very reactive, whereas metallic zinc creates an oxide layer, which doesn't react with oxygen or halogen.

ZINC CARBONITE (ZINC PATINA)
Thin, compact, and stable film on galvanized coating after a natural weathering process, where wet and dry cycles take turns. Complete formation takes 6-12 months and during the process galvanized coating will turn a matte gray color. Remarkable impact on corrosion protection.

ZINC COATING
Zinc layer on a steel surface to protect steel from corrosion and hence increasing the lifetime of products made of steel. Normally zinc coating is almost pure zinc, zinc content more than 99% by mass.

ZINC FLAKE COATING
Inorganic liquid-based coating consisting of a mixture of zinc and aluminum flakes. Zinc flake coating is applied to base metal non-electrolytically, and it provides a durable corrosion protection. Zinc flake coating is often better known by a brand name, such as Geomet or Dacromet.

[31)] Simoneau R.W. 2008. Defining Sustainability via ISO 14001. Mat Ed Resource Center.

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