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Earthquake protection for switchgear systems

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In order to avoid damage in the event of an earthquake, buildings and technical infrastructures need to be designed to be ‘earthquake-proof’ wherever possible. This means that switchgear manufacturers faced with the demands of earthquake safety are confronted with something that is not an everyday occurrence and which requires expert know-how. But what should be done if a switchgear unit needs to be earthquake-proof? This guide is intended to help the switchgear manufacturer gain a basic overview, precisely for this and similar cases.

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1 Introduction

Natural forces have always posed a threat to humans and repeatedly cause numerous deaths and serious damage to property. Whilst extreme meteorological occurrences, such as storm surges, floods and heat waves, can be forecast relatively accurately these days, earthquakes remain relatively difficult to predict. This is one of the reasons that seven of the eleven natural disasters (see tab. 1) that caused the highest death tolls between 1980 and 2013 stemmed from earthquakes [Mun14].

Date	Result	Magnitude	Region	Fatalities
12.1.2010	earthquake	7.0	Haiti	222,570
26.12.2004	earthquake, tsunami	9.1	Sri Lanka, Indonesia, Thailand, India, Bangladesh, Myanmar, Maldives, Malaysia	220,000
2.–5.5.2008	cyclone nargis, storm tide	–	Myanmar	140,000
29.–30.4.1991	tropical cyclone, storm tide	–	Bangladesh	139,000
8.10.2005	earthquake	7.8	Pakistan, India, Afghanistan	88,000
12.5.2008	earthquake	5.8	China	84,000
July/August 2003	heat wave	–	Europe	70,000
July/Sept. 2010	heat wave	–	Russia	56,000
20.6.1990	earthquake	7.4	Iran	40,000
26.12.2003	earthquake	6.6	Iran	26,200
11.03.2011	seaquake	9.0	Japan	18,537

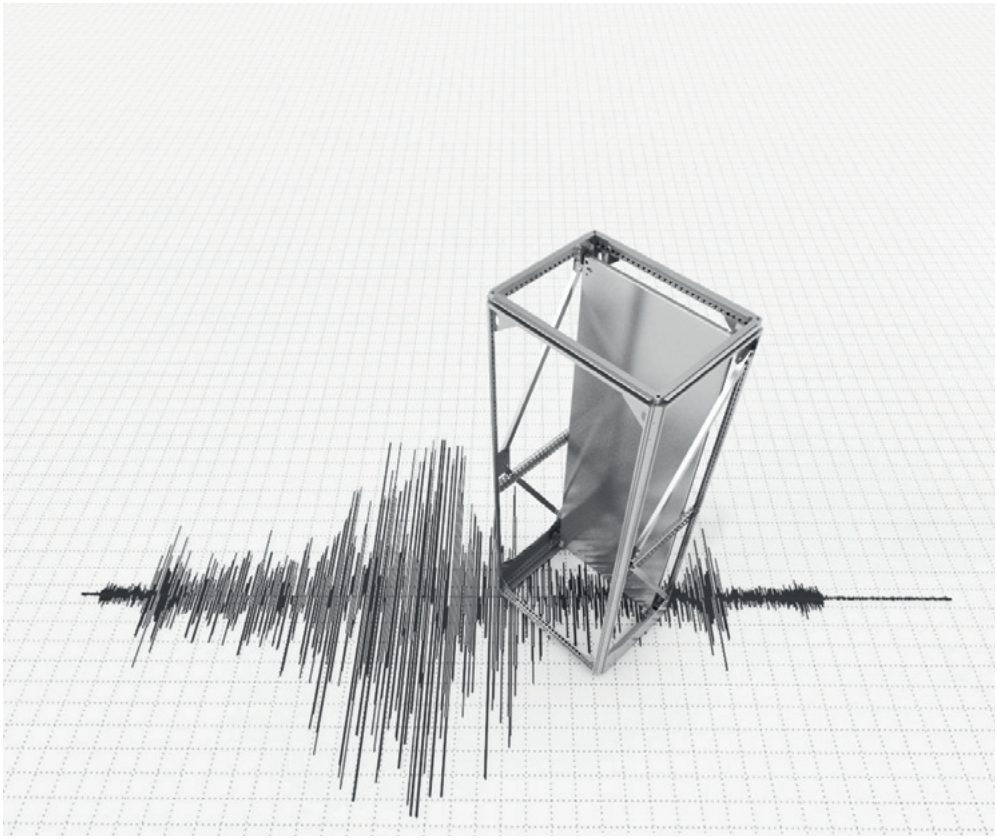
Table 1: Fatalities of natural disasters from 1980 till 2013

Earthquakes occur as the result of processes taking place below the surface of the Earth. The Earth's solid crust, which is made up of plates, moves over its liquid core – a process and due to magma movement known as plate tectonics. These plates move toward, away from or along each other at their boundaries. As they catch on each other during these movements, immense pressure builds up. A sudden release of this energy is what causes an earthquake, which can cause great damage over considerable distances according to the magnitude of the force involved.

Earthquakes usually cause structural damage to buildings and the transportation infrastructure, which sometimes arises as a result of secondary events such as landslides or tsunamis. However, very serious damage can also occur to buildings' internal systems. Depending on the magnitude of the earthquake and the population of the affected region, this can certainly rival the severity of the afore-mentioned damage to buildings and transportation infrastructure. Damage to the technical infrastructure often also interrupts the electricity, drinking water, gas supply etc. in the aftermath of the actual earthquake. Immediately following an

earthquake, when aid is most urgently needed, damage to the transportation and technical infrastructure can hinder assistance efforts.

To avoid the kind of damage described above, buildings and the traffic and technical infrastructures in areas prone to earthquakes should be designed to be “earthquake-resistant”. However, the appropriate measures not only differ significantly depending on the area in question (buildings, technical infrastructure), but the risk of an earthquake happening also needs to be taken into account. In other words, a particularly earthquake-prone area will require correspondingly stricter measures. This white paper provides a broad outline of the meaning of “earthquake-resistance” in specific relation to the electrical infrastructure.



2 Is the switchgear system earthquake resistant?

When it comes to earthquake protection, building safety is often the primary concern. This is certainly understandable, as primary earthquake damage to buildings generally causes the most fatalities, and the majority of damage to property also occurs this way. However, technical infrastructure installations such as electrical switchgear systems and data centers also require effective protection against earthquakes. This not only applies to critical systems, such as those in power plants or production facilities in the chemical industry, but may also be important for all systems of the general supply.

2.1 What needs to be done?

Switchgear manufacturers called to consider earthquake-resistance requirements are confronted with issues beyond the scope of their regular business. What has to be done if a customer needs an earthquake-resistant switchgear system, for instance? This guide provides advice for this and similar scenarios to help switchgear manufacturers gain a general idea of the issues involved.

2.2 What needs to be considered?

What needs to be considered when constructing electrical switchgear systems in regions that are potentially earthquake-prone? This is the key question. To provide a clear insight into the problems involved, the paper starts by explaining a number of basic principles relating to earthquakes, their measurement and the different scales applied. The next section examines the effects an earthquake can have on electrical switchgear systems and the damage it can potentially cause.

2.3 Which standards are applicable?

There are a number of standards and regulations relating to earthquake protection. As already stated, building safety is often the primary concern. In certain regards, the standards adopt very different approaches according to the scientific discipline – civil engineering, electrical engineering or information technology. This white paper provides an overview of the different standards relating to the electrical infrastructure.

3 Intensities, magnitudes and earthquake zones

In terms of physics, an earthquake is a shock wave that emanates from the epicenter of the earthquake. This shock wave causes the Earth's crust to vibrate with a complex frequency spectrum, both horizontally and vertically. This is described in terms of the relating amplitudes and frequencies on the Earth's surface. Because the energy released by an earthquake cannot be measured directly, we use various scales to describe the strength of an earthquake. This includes differentiating between scales of intensity and scales of magnitude.

3.1 Subjective intensity scales

Intensity scales are based on the macroscopic effects of an earthquake – such as the severity of damage to buildings – and the subjective impressions of the people who feel or hear the earthquake. A frequently used scale to indicate the intensity is the **Mercalli scale,** which was developed in 1902 and is still in use today (see tab. 2). Scales of intensity can only be used to a limited extent in sparsely populated areas where there are few buildings where damage might occur and not many people to report their experiences.

JMA	Mercalli				
Level	Soil Acceleration			Description	Level
	gal	gal	g (9.81 m/s^2)		
0	< 0.8				
		< 1.0	< 0.001	instrumental	I
1	0.8–2.5				
		1.0–2.1	0.001–0.002	feeble	II
2	2.5–8.0	2.1–5.0	0.002–0.005	slight	III
		5.0–10	0.005–0.01	moderate	IV
3	8.0–25	10–21	0.01–0.02	slightly strong	V
		21–44	0.02–0.05	strong	VI
4	25–80				
		44–94	0.05–0.1	very strong	VII
5	80–250				
		94–202	0.1–0.2	destructive	VIII
6	250–400				
		202–432	0.2–0.5	ruinous	IX
7	> 400				
		over 432	0.5–1	disasterous	X
			1–2	very disasterous	XI
			> 2	catastrophic	XII

Table 2: Mercalli Scale compared to the Japanese JMA Scale

Note: Seismic intensity is not regulated based on acceleration only. Therefore this table is just for reference.

3.2 Measuring technology for earthquakes

Scales of magnitude are based on measurements taken by seismometers, which measure the local vibrations in the Earth's surface in terms of speed, acceleration and displacements. Calculations using these measurements can indicate the strength of the earthquake. The best-known scale of magnitude is the Richter scale, which was developed in the 1930s and is still used today for this purpose. The magnitude according to the Richter scale is calculated using measurements taken by a special kind of seismometer near to the earthquake's epicenter (at a distance of 100 km), which is why it is also frequently called the 'local magnitude scale'. Because of the specific type of seismometer its inventor Charles F. Richter used, the Richter scale has a maximum value of 6.5 and, strictly speaking, only applies to the U.S. federal state of California. Higher magnitudes, which the media often also cite as being measured on the open-ended Richter scale, are really moment-magnitude values along a modern extension of the Richter scale. The strongest ever recorded earthquake with a magnitude of 9.5 occurred in Valdivia, Chile, in 1960. In comparison, the earthquake in Japan that caused the reactor disaster in Fukushima in 2011 had a magnitude of 9.0.

3.3 The probability of an earthquake is important for risk assessment

Besides categorizing earthquakes according to strength, i.e. their intensity or magnitude, another important aspect is the probability that an earthquake of a given strength will occur. Earthquake risk zones are defined in order to facilitate a reasonable risk assessment. For instance, there are five earthquake zones in the United States. Zone 0 is where strong earthquakes can be practically ruled out, whereas earthquakes of quite a large magnitude are relatively probable in zone 4. Parts of the U.S. federal state of California are typical examples of earthquake zone 4. The requirements relating to earthquake protection for IT and telecommunications installations, and for electrical infrastructure installations, are often based on these earthquake zones.

However, zoning varies from country to country. In most countries in Europe (including Germany), the zones range from 0 to 3; but up to five zones might be categorised. This is further complicated by the lack of uniformity between the national standards that define the zones (see tab. 3). Thus it is not possible to draw a simple comparison between national standards at face value. However, classifying earthquake zones is important when it comes to delivering

earthquake-resistant systems, as the appropriate measures – incurring additional costs – need only be taken in high-risk areas.

Country	AT	GER	CH	FR	IT	GR	USA
Standard	ÖN 1998-1	DIN EN 1998-1	SIA 261	NF EN 1998-1	OPCM 28	Gna 1998-1	1997 UBC
Zone 0	a < 0.035 g	0.0 g					0.0 g
Zone 1	0.035 g < a < 0.05 g	0.04 g	0.06 g	a < 0.07g	a < 0.05 g	a < 0.16 g	0.075 g
Zone 2	0.05g < a < 0.075 g	0.06 g	0.1 g	0.07 g < a < 0.11 g	0.05 g < a < 0.15 g	0.16 g < a < 0.24 g	0.15 g
Zone 3	0.075 g < a < 0.1 g	0.08 g	0.13 g	0.11 g < a < 0.16 g	0.15 g < a < 0.25 g	0.24 g < a < 0.36 g	0.3 g
Zone 4	0.1 g < a		0.16 g	0.16 g < a < 0.3 g	0.25 g < a < 0.3 g		0.4 g

Table 3: Soil acceleration in Europe and in the USA

4 Earthquake damage to the electrical infrastructure

In order to evaluate the relevance of earthquake protection for electrical installations, an overview must first be established of the damage that can potentially occur in an earthquake, including any consequential damage that might arise if an electrical system fails. Damage to buildings is usually the focus of attention following an earthquake. Depending on the kind of building involved, the values for the systems installed in it are often higher than for the structural elements themselves. It makes sense, therefore, to look beyond the earthquake-resistance of the building alone and to also consider the potential requirements regarding its systems in the case of an earthquake.

It is particularly important that the installations of critical, safety-relevant infrastructures, such as in nuclear installations, remain operational even after high-magnitude earthquakes. This calls for a very extensive range of measures, which are beyond the scope of this white paper. A high level of systems availability, and thus robust protection against earthquakes, is also particularly vital for telecommunications and IT. At the same time, the ability of installations to remain operational for a given time or to resume service quickly are also important issues following an earthquake.

The frequency of the vibrations that occur during an earthquake generally ranges between 0.3 Hz and 50 Hz. The stresses these vibrations exert on a switchgear system can cause both malfunctions and structural damage to the entire system. Malfunctions can be remedied with little delay, so a switchgear system can be put back into service relatively quickly following an earthquake. This might typically involve a loose contact or temporary short-circuit that is interrupted by the installation's safety systems.

More disruptive damage might include the dislocation of components from an enclosure's support rail or mounting plate. Serious damage to the switchgear system generally causes a protracted interruption to the energy supply – say, if the earthquake were to move an enclosure, perhaps dislodging it from its anchoring or even tipping it over.

This category also includes any structural damage to the enclosure. Enclosures play an extremely important role because if they cannot withstand the earthquake, the entire system is going to fail. This makes earthquake protection for enclosures a key factor in all the relevant standards. However, this aspect can never be considered in isolation, but rather the surrounding building and all the installed components must also comply with the relevant requirements as well. Thus a suitable enclosure alone will not suffice if the system needs to remain operational after, or even during, an earthquake. In addition, the installed components must also meet the requirements of the appropriate standard and the functioning of the entire system must be proved under test conditions.

5 Overview of current standards

Earthquake protection is important from various points of view. Correspondingly, different standards are applied depending on the technical discipline concerned. These standards can be roughly divided into the categories civil engineering, IT and telecommunications, and electrical engineering. Furthermore, the applicable standards also differ according to the geographical location of the market. Building standards play a small role in the construction of earthquake-resistant electrical switchgear systems, they are not described in great detail here. However, as electrical systems are for the most part installed in buildings, these standards also play a certain role. For building standards the main focus is often on the floor mounting of the enclosure. Though, for an evidence of the floor mounting knowledge of the installation side's condition are necessary. Therefore the evidence is done by a building expert. Some of the standards that apply to electrical engineering and IT and telecommunications have their origin in a building standard but transfer them into specific requirements for the related equipment. For instance, buildings can actually amplify the effect of an earthquake, potentially further increasing the amplitude and accelerations that are exerted on an electrical system.

Three specific sets of standards are particularly relevant to switchgear systems and other electrical engineering and information technology infrastructures – DIN EN/IEC 60068-3-3, IEEE 693 and Telcordia GR-63-CORE. Other standards, for example from the construction industry, are generally not relevant to switchgear production. It can be assumed that structural engineers will comply with these standards. Only the interface between construction and electrical engineering – where the building and enclosure meet – plays a certain role. This means that references to the respective building standards also appear in various standards.

DIN EN/IEC 60068-3-3

IEC 60068-3-3, identical to DIN EN 60068-3-3 [Beu93] in Germany and Europe, is primarily a guideline for checking electrical devices for seismic resistance. The standard distinguishes between a general and a specific seismic class. The specific seismic class should be used where knowledge of the seismic movement exists based on the local geographical situation or the building in which the device is to be installed.

IEEE 693

The 693 [IEE05] standard issued by the Institute of Electrical and Electronics Engineers (IEEE) specifies the parameters for earthquake-resistant switchgear. It defines the test methods for complete switchgear systems and for individual components such as power circuit-breakers. Besides test methods, the standard also contains guidelines for designing earthquake-resistant switchgear in relation to buildings, foundations and fixing enclosures to the floor. Thus reference is also made to building standards in this document.

Telcordia GR-63-CORE

Although the GR-63-CORE [Tel02] generic requirements originally developed by Bellcore – now Telcordia – for telecommunications are not a formal standard as such, they form a very commonly stipulated requirement in contracts, especially in the United States. The basic premise is that systems – such as data centres – need to offer a high level of structural resilience to various influences such as moisture, fire, pollutants and earthquakes. The document refers to the designated zones in the United States (zones 0 to 4), where zone 0 represents a very low risk and zone 4 a high risk of earthquakes (see table 3). In order to ensure high system availability, the requirements in zone 4 are correspondingly higher than in zone 0. These requirements are very high and can therefore also be found in other standards (e.g. IEC 60068-3-3, DIN EN 61587-5 (RRS for uniaxial acceleration), ETSI EN 300019-1-3).

6 Typical test methods

There are in general two possibilities to design systems in earthquake-prone areas. The first possibility is to test the complete switchgear system with the desired configuration – including all components installed in the enclosures- in a suitable laboratory. This option is quiet cost and time consuming and according to Rittal's experience is only required only by a small number of users. In the second option the control or switchgear manufacturer uses components (incl. enclosures) which proof a principle qualification for earthquake-prone areas. For this proof Rittal has tested exemplary its enclosures of the TS 8 type series in approved laboratories. For this proof the enclosures are tested according to a defined test method in regard to a principle qualification for the use of the enclosure in earthquake-prone areas. The following chapters detailed describe a typical testing method for enclosures earthquake-resistance. The vast majority of users choose this less costly way.

All the applicable standards prescribe tests on a vibrating table to demonstrate an enclosure's earthquake resistance. The aim is to simulate the effects of an earthquake – i.e. vibrations and shock stresses – in the laboratory. The test piece is mounted onto the vibrating table, where it is subjected to a pre-defined test program. The test piece must not incur any structural damage as a result, meaning that no load-bearing parts may be damaged, warped, broken, etc. In addition, no important connections should separate. The same also generally applies for enclosure doors, hinges and locks. Functional tests are then performed – to ensure that the system still functions as required post-stress.

6.1 Different frequency spectra in the standards

The precise test requirements vary according to the standard in question, particularly regarding the exact frequency spectrum and related accelerations. The test method specified in Telcordia GR-63-CORE is outlined here as an example. First, the enclosure is mounted on a vibrating table and fitted with acceleration and path recorders in its centre and on top. During the test, the enclosure must be loaded to an extent that simulates a real installation. The tests are then conducted by running a specified program that reaches the defined acceleration values at frequencies of between 1 Hz and 50 Hz (the so called Required Response Spectrum (RSS)). The incoming spectrum, the so called Transmissed Response Spectrum (TRS), on the test piece is the key. This depends on the way the test is set up and on the mass and geometry of the test piece. The displacements of the test piece, measured in its centre and at its top, must not be greater than 75 mm (3 inches) at any point during the test.

The vibration table tests described above are performed in all three dimensions. The RRS prescribed in GR-63-CORE lasts 31 seconds in each dimension. The loads exerted on the enclosure during these tests correspond approximately with those experienced during an earthquake with a strength of 8.3 on the moment-magnitude scale.

6.2 Very similar test spectra

In order to compare the requirements of the vibration table tests in all three relevant standards, the required RRS can be plotted in an acceleration-frequency diagram (see fig. 1). This reveals that the spectra applied in the individual standards are quite similar but have different acceleration values in the relevant areas. It also becomes apparent that zone-4 certification according to GR-63-CORE almost completely meets the requirements of the other two standards.

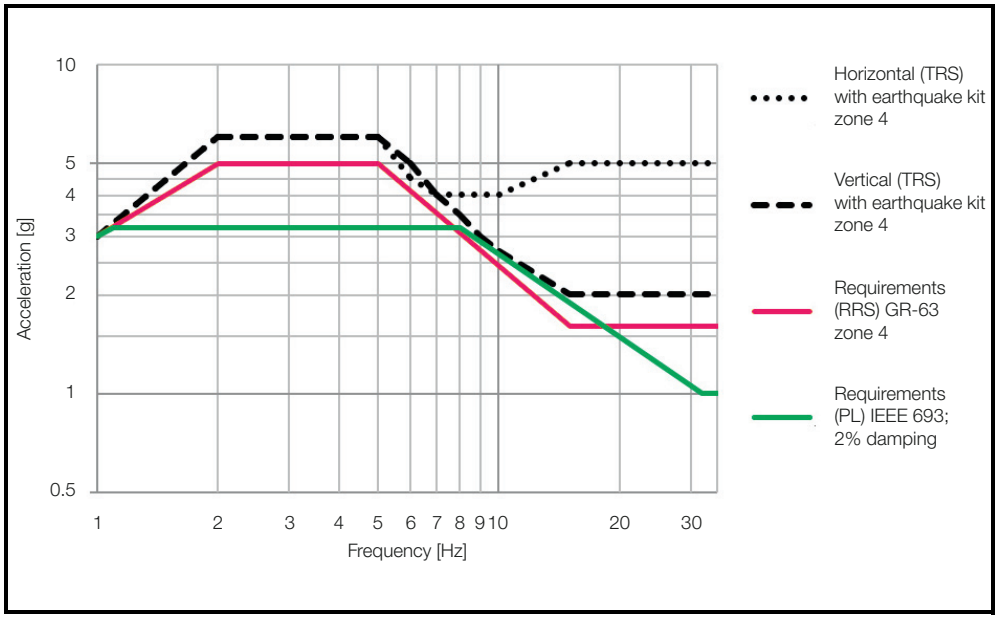


Figure 1: Acceleration-Frequency-Diagram

7 Earthquake-resistant enclosure

One method of building stable mechanical constructions able to withstand tremors, which has continued to prove itself since ancient times, is half-timbered constructions. This uses poles that are bound together at the ends to form triangles. As a result, the forces exerted on the poles are almost exclusively compression or tensile forces, which make the entire construction extremely sturdy and also reduce its weight. This principle has proved a successful way to construct houses, bridges and other load-bearing structures. These days, the norm is to provide buildings with as rigid a structure as possible, for example using solid concrete constructions. Another approach, which is particularly prevalent in high-rise buildings, is to use a pendulum as an active element. An earthquake's movements make the pendulum swing, which absorbs almost all of the energy so that no damage occurs to the building's structures. As a third possibility the object that shall be protected can be decoupled from the earthquake that means systems that absorb the force or disengage the meeting point. Whereby a building or equipment is not firmly fixed to the ground, but instead stands on dampers, which shield the building from most of an earthquake's accelerations. In this case tt is necessary that the weight which shall be dampened is exactly known and there must be enough spring/damping deflection available.

Rittal also uses the half-timber principle to make its TS 8 enclosure earthquake-resistant (see fig. 2). This standard enclosure, which was launched in 1999 and hit the ten million production mark last year, is used all over the world in a wide variety of sectors.

The unit is robust and exceptionally flexible, efficient and high-quality. The optional extra earthquake accessory stiffens the construction of the TS 8 enclosure frame to comply with even the strict zone-4 requirements of GR-63-CORE. The earthquake kit consists of stays that are screwed into the sides of the enclosure's frame to significantly increase its rigidity. Gusset plates in the corners of the frame add extra stability. The mounting plate is also more rigid and screwed to the stays.

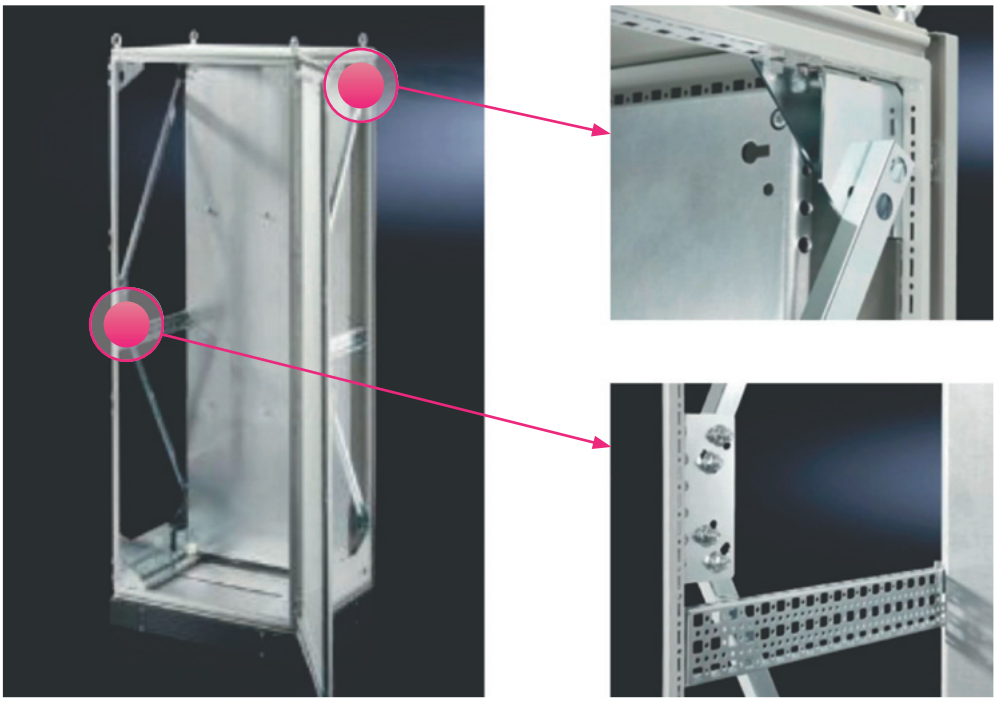


Figure 2: Earthquake extension accessories for the TS 8

A more stable plinth is also available for fixing the enclosure to the floor for earthquake protection. Three sizes of the TS 8 standard enclosure were tested for conformity with the zone-4 requirements of GR-63-CORE by the independent body EQE International Ltd. at the University of Bristol and IABG in Ottobrunn. When fitted with the special earthquake accessories (consisting of earthquake kit, earthquake plinth and comfort handle), the enclosure achieved zone-4 certification with contents weighing up to 500 kg on its mounting plate.

In addition it was certified that the TS 8 meets the requirements of zone-3 GR-63-CORE without any special accessories, up to a maximum weight of 152 kg.

The tests were performed on TS 8 enclosures with dimensions 600 mm x 2,000 mm x 400 mm, 600 mm x 2,000 mm x 600 mm and 800 mm x 2,000 mm x 600 mm (WHD) (see fig. 4). The enclosure's certification is basically valid for these three sizes with the load actually tested.

But since Rittal successfully has tested several serial – supported by tests of customer specific types – a fundamental ability of the engineering principle behind the frame structure and the enhancing earthquake structure can be assumed. Thus, also other dimension can be considered as reliable for earthquake requirements, as long as the following criteria are met:

– The earthquake standard/the frequency spectrum is comparable (vgl. see fig. 1)
– Even weight distribution
– Mounted weight of components equal or less than the tested variants
– Base area equal or bigger than the tested variants
  (bigger base area improves relationship of the levers)
– Height w/o plinth not bigger than 2000 mm
  (or rather the center of mass higher than 1000 mm)

Model No.	**Dimensions** (W x H x D) mm	**Measures**	**Tested installed weight** kg	**Standard, level**
8806.500	800 x 2,000 x 600	Standard	152	Telcordia GR-63-Core, Zone 3
8806.500	800 x 2,000 x 600	comfort handle, earthquake kit, earthquake plinth	500	Telcordia GR-63-Core, Zone 4
8604.500	600 x 2,000 x 400	comfort handle, earthquake kit, earthquake plinth	500	Telcordia GR-63-Core, Zone 4
8606.500	600 x 2,000 x 600	comfort handle, earthquake kit, earthquake plinth	500	Telcordia GR-63-Core, Zone 4

Table 4: Tested variants of TS 8

Rittal can assist here in advisory capacity and for limit areas Rittal together with the customer can develop a qualified solution.

8 Specific Approach

Even armed with this information about earthquakes, potential damage and the standards that exist, the question remains as to how to respond to a specific inquiry about earthquake-resistant switchgear. First, the geographical location needs to be clarified – for which country and which earthquake zone is the switchgear required? Then the relevant standard needs to be identified to suit this requirement. All requirements relating to the building or anchoring of the switchgear within the building must be taken into consideration by the parties responsible for the construction and structural design.

In respect of the above-cited examples of application standards, a distinction has to be made between structural integrity and maintaining the function of a system. If the sole concern is structural integrity, then a certified enclosure, such as the TS 8 enclosure fitted with the appropriate earthquake accessories, as described in the previous section, will generally suffice.

Continuous functioning of a system, as is sometimes required, cannot be guaranteed by an enclosure, of course. Extensive tests are required to ascertain this aspect. Finite-element-method structural calculations also can be made in advance. It is important to test the switchgear with the contents that are actually going to be fitted. The distribution and weight of the installed components can influence the vibration behavior of the enclosure. The way the enclosure is installed – whether on mounting plates, top hat rails or variable bus bar systems – can also affect its behavior. For this requirement it is therefore advisable to test earthquake-resistant enclosures for each specific scenario, in other words with the intended contents in place.

9 Summary

Earthquakes can represent a very serious danger to people and property in certain geographical locations. Electrical switchgear systems and data centers are not only very valuable property, but their key role in the technical infrastructure makes them particularly vital – hence the need to ensure their earthquake-resistance in risk-laden geographical regions. Enclosures – generally those containing switchgear and servers – play a key role in ensuring the continuous functioning of such a system in the event of an earthquake. After all, if these suffer serious structural damage, then this will undoubtedly disable the system.

This makes earthquake-resistant enclosures extremely important. Various standards define the requirements such enclosures have to fulfill in order to qualify as earthquake-resistant. Different standards apply depending on the particular application and geographical market. Even though they adopt different approaches, they have one key aspect in common – the vibration test on a vibration table, which simulates the accelerations caused by an earthquake. The precise frequency and acceleration spectrum does vary to a certain extent from one vibration table test to another, however.

The TS 8 enclosure manufactured by Rittal with its optional earthquake accessories has been tested and is certified as meeting the highest, zone-4 requirements of Telcordia GR-63-CORE.

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