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EARTHQUAKE RESISTANCE OF POLES ALONG ROADS

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Abstract

Earthquakes pose a significant threat to roads and infrastructure facilities. The collapse and damage of poles along roads due to earthquakes can pose a danger to road users and an obstacle to rescue services. The paper analyzes the influence of the material of construction and the type of pole foundation on the behavior and damage of poles during an earthquake. The paper first presents the types of poles according to their material of construction. The characteristics of steel, aluminium and composite poles are presented. The behavior of poles and damage during an earthquake depend on the material of the pole, the weight and length of the pole, and other limitations such as the cables carried by the pole. It has been shown that greater damage occurred in concrete poles than in steel poles, and an even better solution is aluminium and composite poles. The following shows the influence of the method of pole foundation (soil and rigid) on the behavior and damage of poles during an earthquake. Finally, an example of increasing the seismic resistance of poles is presented. Past earthquakes have shown that damage to roads and infrastructure facilities can prevent all forms of assistance to the injured. It is crucial that transport infrastructure is functional after an earthquake. Therefore, rapid inspection of affected transport infrastructure (roads, railways, bridges, tunnels, airports and seaports) is essential. The use of earthquake-resistant poles ensures safer transport during and after an earthquake. They can keep key transport routes open for rescue and relief operations and minimize the need for frequent repairs and reconstruction, which reduces maintenance costs. By integrating earthquake-resistant poles made of energy-absorbing materials, cities can build resilient transport networks.

Keywords: earthquake, road infrastructures, poles, materials, damage of poles, energy absorbing, resistance

1. Introduction

Earthquake engineering is an interdisciplinary area aimed at designing and analysing structures that are capable of responding to destructive seismic action. The primary focus of earthquake engineering is on high-rise structures, but no lesser significance is given to infrastructure facilities which must also be designed to withstand seismic action when located in seismically active areas [1].

The earthquake poses a significant threat to roads and infrastructure facilities, such as gas, water and electricity supplies. The impact of earthquake on roads can result in economic losses, delayed emergency responses and reduced connectivity for affected regions, Fig. 1.

Figure 1. Road damages [2]

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After an earthquake, it is very important that the transportation infrastructure is functional within the first 24 hours, and for any damage to be repaired within the first 72 hours. All means of transport must be used to quickly reach people trapped under collapsed and partially collapsed buildings. Injured people pulled from under the rubble must be quickly transported to hospitals. Furthermore, a large number of construction equipment and trucks are being sent to the earthquake-affected area to remove debris. Due to the increased traffic, temporary measures are needed to repair road damage in a short time [2].

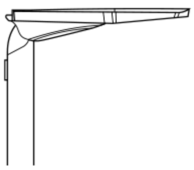
Earthquakes can also cause collapse and damage to poles along roads, Fig. 2, which can pose a danger to road users during an earthquake and an obstacle to rescue services after an earthquake. For example, in the 2004 Chuetsu earthquake in Niigata Prefecture, with a recorded maximum seismic intensity of 6.9 on the Richter scale, a total of 3,401 utility poles carrying communication cables were toppled, broken, or tilted [3]. Most of the damage in Niigata occurred because the poles had been installed on weak ground, so they were damaged by ground movement.

First measure in the restoration of communication and maintenance of safety is the repair of collapsed, broken, or leaning utility poles. Experience has shown that damage to poles after earthquake depends on many parameters, such as the pole material, the purpose of the pole, the location of installation, the type of foundation, etc.

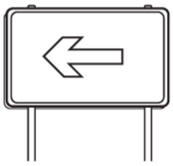
Figure 2. Utility poles damaged by landslide [3]

2. Types of poles along roads

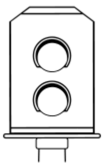
Poles placed along roads play a key role in the traffic system. Their primary function includes traffic safety, navigation, lighting and marking of traffic rules. Among the most common types of columns are those that carry lighting fixtures, traffic signs, traffic lights, navigational markers and cameras, Fig. 3.



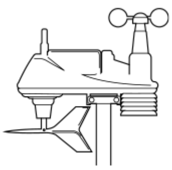
Lighting columns



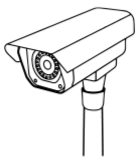
Traffic sign columns



Traffic signal columns



Columns for monitoring meteorological conditions



Camera columns

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Figure 3. Roadside columns [4]

Poles along roads are usually made of steel, aluminium, steel-reinforced concrete, composite materials and wood [5]. The choice of material depends on the type of road, local conditions, costs, as well as aesthetic and safety requirements.

2.1 Steel poles

Steel is the material most commonly used to make roadside poles. Steel poles are relatively lightweight, durable with appropriate anti-corrosion protection, affordable, and have high resistance to material fatigue [6]. It is important to regularly carry out inspections and maintenance on steel poles to ensure their proper functioning over a longer period. The advantage of steel poles is that they are completely recyclable. Steel recycling is an environmentally friendly and efficient process that reduces the need for new steel production, thereby significantly reducing the negative impact on the environment.

Anti-corrosion protection of steel poles is very important in the event of an earthquake because corrosion can weaken the structure, so the column may not behave as designed during an earthquake.The most commonly used method for protecting poles from corrosion is hot-dip galvanization, in which steel elements are immersed in a molten zinc solution at a temperature of around 449°C to create a strong and resistant coating [7]. Magnelis steel, as an innovative product obtained through the hot-dip galvanizing process with an adjusted composition of the liquid into which the steel elements are immersed, which, in addition to zinc, also includes 3.5% aluminum and 3% magnesium [8], is definitely worth mentioning. This superior coating gives Magnelis exceptional corrosion resistance and self-healing at points of damage, unlike standard galvanized elements. Owing to this characteristic, Magnelis is a long-lasting material and as such becomes a more economical alternative to more expensive materials such as stainless steel and aluminum, which can result in significant savings in the project. As Magnelis contains lower amounts of zinc compared to products obtained through the classic hot-dip galvanizing process, Magnelis is also a better choice for the environment.

In addition to hot-dip galvanization, other processes are used to protect steel poles from corrosion, such as zinc silicate protection, metallization, painting, etc. A good method of anti-corrosion protection is the use of weathering steel, which is produced using alloys such as copper, chromium, nickel, etc., which will oxidize and create its own anti-corrosion protection [9]. Fig. 4 shows the steel poles.

Figure 4. Steel poles [10]

2.2 Aluminium poles

Aluminum poles (Fig. 5) generally have numerous advantages over poles made of steel and concrete. The weight of aluminum poles is 1/3 less than steel poles, which results in lower transportation costs, as well as simpler and faster installation.

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Due to a natural layer of aluminum oxide that creates a protective barrier in contact with oxygen, aluminum is naturally resistant to corrosion. When aluminum poles are scratched or dented, the protective layer re-forms. These poles are the only 'self-maintaining' poles on the market in terms of surface treatment [4]. Due to these characteristics, aluminum poles are an excellent solution for coastal areas where there is a greater possibility of corrosion. Aluminum poles are usually supplied unpainted and retain their natural shiny finish, so no painting or repainting is required during use, which reduces maintenance costs. The designed lifespan of aluminum poles is 50 years, which is twice that of most steel or concrete poles. Since aluminum is fully recyclable and long-lasting, it fulfills many requirements that other materials cannot.

Figure 5. Aluminum lighting poles [11]

2.3 Composite poles

Poles made of composite materials (Fig. 6) are the most expensive alternative to traditional poles, but they have excellent energy absorption properties. By definition, composite materials consist of different materials (metals, ceramics, polymers) firmly bonded together to create a new, different material with physical or chemical properties that exceed those of the individual components [12]. More recently, with the development of polymer materials, composite lighting poles are produced from fiber-reinforced polymer resin [13].

Composite poles have numerous advantages over poles made of other materials, such as higher tensile strength, lower weight, fire resistance, excellent electrical insulators, resistance to adverse environmental influences (water, chemicals, salt). Therefore, they are less susceptible to corrosion and do not require maintenance. The life cycle of composite poles is up to 80 years, which is twice as long as the average life cycle of poles made from other materials [14]. Composite poles do not require carcinogenic protection or other chemicals, which makes them environmentally friendly because there is no leaching of protective coatings, especially in areas near national parks, water sources, etc.

Due to their advantages, composite poles are an excellent choice for areas where extreme conditions such as hurricanes, typhoons, and tornadoes may occur, as well as areas where there is a greater risk of earthquakes, fires and ice storms, etc. The use of this type of pole is desirable in areas where traditional poles are not satisfactory in terms of durability. For example, in areas with high groundwater levels or high average rainfall, rotting and reduced load-bearing capacity of wooden poles may occur. Since the surface of composite poles does not absorb water, such poles are not susceptible to rotting or decay. In coastal areas and on roads where salting is performed in the winter months, there is a high probability of corrosion in steel poles, while in reinforced concrete poles, the steel reinforcement inside the pole may crack due to corrosion. Salt does not permeate composite poles, and owing to the waterproof

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surface, the poles will maintain their characteristics over time. Compared to poles made of other materials, if we look at the initial investment, composites are classified as more expensive alternatives, but their use results in savings over the entire life cycle of the pole.

Figure 6. Composite pole [15]

2.4.The influence of the type of pole on damage after an earthquake

The behavior of a column during an earthquake and the damage after an earthquake depends on the column material, weight and length of the pole and on other constraints such as cables it supports. It has been shown that greater damage occurred in concrete poles than in steel poles. A better solution is aluminum and composite poles due to their ability to deform and absorb more energy.

Most of the damage to concrete poles was attributed to their high weight compared with steel poles. Long and heavy concrete combination poles, which carry communication lines together with electrical lines, suffered greater damage compared to concrete poles carrying communication lines only.

Furthermore, pole damage also depends on the position of the poles. The greatest damage was on utility poles at which lines originate or terminate, then on utility poles along routes where lines curve, and finally on utility poles along routes where lines are straight.

3. Type of foundation

The backfill type of the pole foundation significantly influences pole behavior during an earthquake. When using foundation in the soil, such as for instance in rural areas, toppled and leaning utility poles can be seen after an earthquake [3]. In places where utility poles are installed beside roads and anchored in hard asphalt adjacent to water-filled paddies, the swaying of the pole tops during an earthquake tends to cause leaning toward the softground side, Fig. 7(a). In such areas, a utility pole that leans over more than the others (utility pole e) pulls down on the adjacent poles (a–h) (Fig. 7(b)) to produce a chain-like effect that results in a series of leaning utility poles. Cracks are usually not seen on the pole that is leaning the most, but are seen on surrounding poles that are leaning only slightly.

If the poles are anchored in concrete or asphalt that completely surrounds them, as is common in urban areas, the poles are less likely to lean. In such areas, horizontal cracks will most often appear near the base of the poles, Fig. 8.

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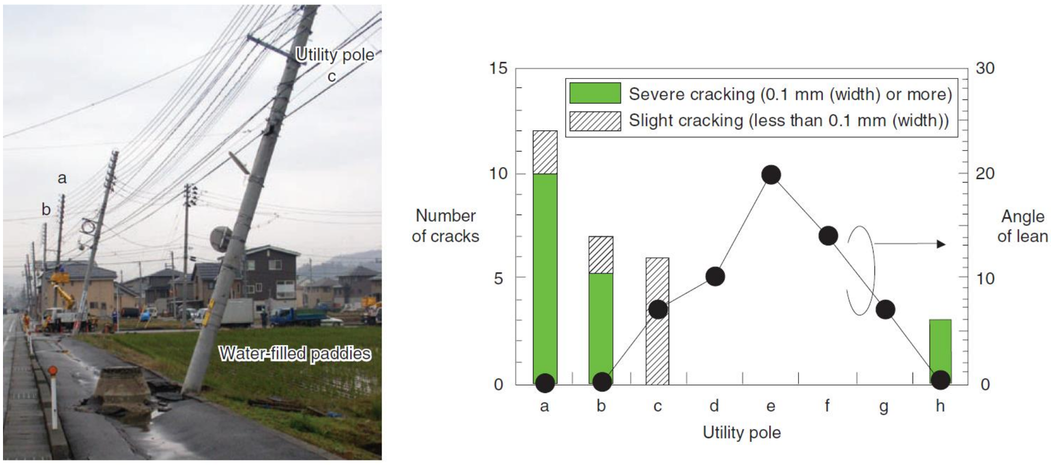

(a) Photograph of damage (b) Damage data

Figure 7. Chain tilting of poles [3]

Figure 8. Horizontal cracking near the base of the poles [3]

4. Increasing the seismic resistance of poles

While seismic resistance of elevated highway bridges (if we looking transportation infrastructure) has been evaluated and upgraded in the seismic codes, most light and utility poles were designed for wind loading and not for earthquake, so their seismic performances were rarely evaluated [16].

Poles along roads are vulnerable to earthquakes due to their slender shapes. They are usually designed to withstand moderate loads at considerable heights [17]. Despite the fact that the loads carried by columns are significantly less than their own weight, the inherent self-weight and thin profile make columns susceptible to lateral forces induced by seismic events [16,18] or wind loads [19,20]. Consequently, various efforts have been made to increase the flexural strength of column structures [21,22].

Traditional base isolation designs configure the bottom of the pole equipment as hinges with restraints. In order to increase traffic safety during and after an earthquake, a solution with use a restrained rocking mechanism at the base of the structure can be applied, Fig. 9. The design leverages the self-centering nature of rocking motion and uses restrainers to control the amplitude of rotation, Fig. 10. Hence, it can effectively avoid tilting of the pole after earthquakes.

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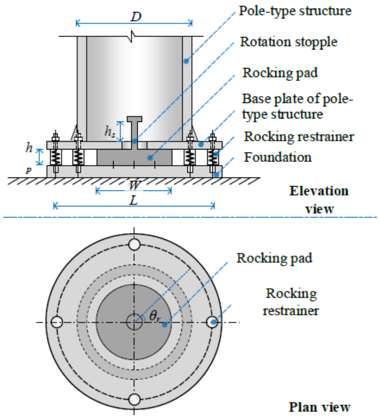

Figure 9. Restrained rocking isolation of pole [16]

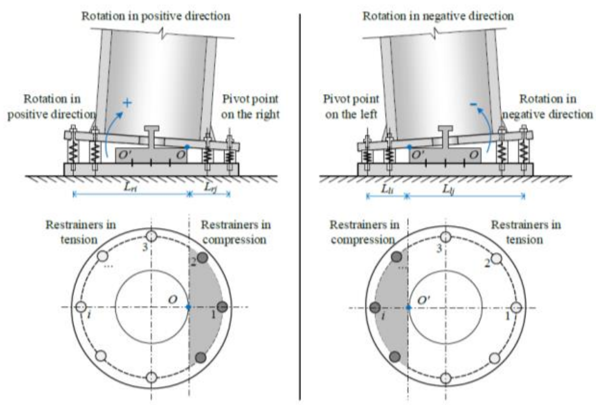

Figure 10. Rocking motion of the isolation device [16]

5. Conclusion

Past earthquakes have shown that damage to transport structures can prevent all kinds of assistance to injured people. It is crucial that transport infrastructure is operational after an earthquake. Therefore, a rapid inspection of the affected transport infrastructure such as roads, railways, bridges, tunnels, airports and seaports is necessary. Collapsed and damaged poles along roads can also pose an obstacle after an earthquake.

The use of earthquake-resistant poles ensures safer transportation during and after earthquakes. They keeps crucial transportation routes open for rescue and relief operations and minimizes the need for frequent repairs and reconstruction, which reduce maintenance costs. Although earthquake-resistant poles cost more due to advanced materials and technology, they save money in the long run by reducing repair and reconstruction costs.

With the increasing frequency of earthquakes around the world, investing in earthquake-resistant road infrastructure is essential. By integrating earthquake-resistant poles made of energy-absorbing materials, cities can build resilient transportation networks. The material used to make the pole has a major impact on the behavior of the poles and their ability to absorb energy during an earthquake.

Adopting earthquake-resistant construction methods will not only protect lives, but will also ensure a more sustainable, disaster-resistant infrastructure for generations to come.

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