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VULNERABILITY OF CRITICAL INFRASTRUCTURE BY NATURAL DISASTERS

Abstract: Natural disasters increasingly threaten the safety of the mankind. Not only that, in past decades there has been an obvious increase in the number of natural disasters, but it is also present an increase in their destructiveness. This results in a higher loss of life, material and non-material damage. In addition, compromising critical infrastructure prevents or limits the implementation of vital state functions (governance, health, education, energy, economic, social, and general security functions), which is further reflected in the safety of states and citizens. Despite the technological development of mankind, societies are increasingly threatened. It is clear that the disasters and their impact on people and critical infrastructure cannot be prevented, but mechanisms for prediction and early warning of disasters can be improved that the resilience and capacity for faster and more efficient revitalization of endangered values and goods can be increased. Besides the degree of destruction, the response strategy in an emergency situation will depend on the type of disaster, but also on the kind of critical infrastructure and specific goods and values that are threatened. In this regard, the paper gives an overview of the scope and the content of (still undetermined) concept of critical infrastructure, the term and the phenomenology of natural disasters, the consequences of geophysical, hydrological and meteorological disasters on critical infrastructure and critical infrastructure protection capabilities against natural disasters.

Key words: *safety, critical infrastructure, natural disasters, the consequences of threats to critical infrastructure by natural disasters, protection of critical infrastructure from natural disasters.*

1. INTRODUCTION

Generally, a disaster is defined as a specific (current, real) threat to humans and their material goods. These are harmful (unfortunate) events with adverse effects on people, property, infrastructure and natural resources, which society cannot overcome without outside help or support resources (Bimal, 2011, p. 12). Therefore this is about "serious disruption of the functioning of society, causing severe financial, economic, social or environmental losses that exceed the ability of affected society to cope using its own resources" (Preet, 2006). Generally speaking, the disasters can be natural, technological, and with complex background (Mladjan, Cvetkovic, 2013, p. 105).

Natural disasters are consequences of mutual influence of natural events (geophysical processes and other processes in nature) and human systems (social-economic, cultural and physical). Consequently, they are different from natural hazards that generate natural disasters only when threaten people and their material goods (Wisner et al., 2004). All natural disasters cause serious damage to critical infrastructures. Natural disasters have, in principle, *polymorphous character* (two instances of the same origin and intensity often produce different total effects), followed by *the phenomenon of parallelism* (affecting only certain geospatial areas where the conditions of life and environment significantly alter) and specific, usually, mass effect (social, health, financial and environmental) (Jakovljevic, Đarmati, 1998, pp. 55-58; Mijalković, 2011, p. 201). This makes it difficult to predict the impact and consequences of natural disasters, particularly to critical infrastructures.

Neither in national law, nor in the strategic documents of the Republic of Serbia, there is a definition of the concept of critical infrastructure. Generally, these are the resources and assets that are essential to the smooth functioning of the economy and society.

The documents of the National Strategy for Protection and Rescue in Emergency Situations, (*Official Gazette of the Republic of Serbia,* No. 86/2011), and the Law on Emergency Situations (*Official Gazette of the Republic of Serbia,* No. 111/2009), do not refer to critical infrastructure at all. However, we can say that the institutional frameworks for the definition of critical infrastructure exist and these are the Sector for Emergency Situations of the Ministry of Internal Affairs of the Republic of Serbia, the relevant ministries and the relevant regulatory bodies. In addition, the specific measures to protect parts of the infrastructure exist, but there is neither a strategy nor protection policy at the national level. The need to consider the safety of critical infrastructure has been identified within the project "Management of Critical Infrastructure for Sustainable Development in the postal, communication and railway sector in the Republic of Serbia" (Gospić, et. al, 2012, p. 3).

According to the Council Directive 2008/114/EC adopted on December 8, 2008, on identification and determination of the European Critical Infrastructures and the assessment of the need for improving their protection in the European Union, the critical infrastructure presents: asset, system or its part that is located in the territory of the Member State and which is necessary for the maintenance of key social functions, health, safety, economic and social well-being, and whose disruption or destruction would have a significant impact on a member state (Council Directive 2008/114/EC on 8 December, 2008).

According to the conclusion of the Euro-Atlantic Partnership Council, the Civil Protection Committee - EAPC CPC 2002, which was later adopted by the *Senior Civil Emergency Planning Committee* - SCEPC, critical infrastructure is consisted of adequate national capacities, services, and information systems that are so vital that their lack of action or damage could have a direct impact on national security, the national economy, public health and safety of people and the efficient operation of government. In addition, critical infrastructure includes (but not exclusively): food, water, agriculture, health care and emergency medical service, energy, transport, information and telecommunications, banking and finance, chemical plants, defense industries, post offices and distribution of goods, as well as national monuments and other cultural values (The Department of Homeland Security, 2002, p. 15; by: Gačić, Proda, 2012, p. 163).

According to the documents of the United Nations, critical infrastructure represents the infrastructure that consists of physical and information technology facilities, networks, services and property, which if collapsed or destroyed can have a serious impact on the health, safety and economic well-being and effective functioning of government (Gačić, Proda, 2012, p. 163).

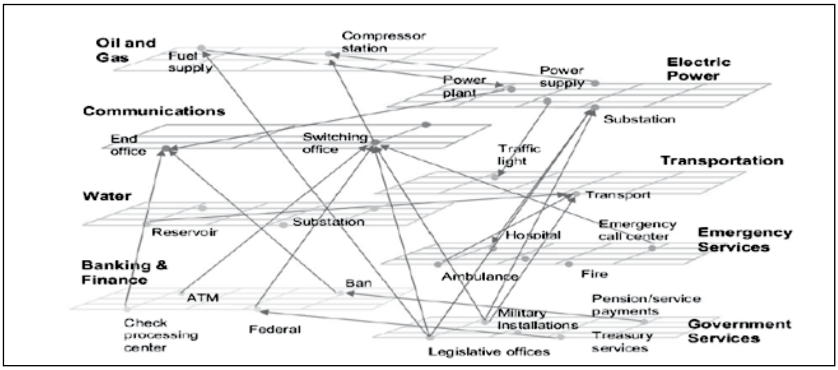

Figure 1: The interdependence of various infrastructures (Rajmohan, et al, 2012, p. 57)

Based on the comparative analysis performed in 16 countries in 2004, the researchers generalising came to the conclusion that critical infrastructure consists of: banking and finance, (tele)communications, information and telecommunication systems, and energy; transport, logistics and distribution; health services, water and water supply; central government/government services; first responders; petroleum products and gas supply; information services, the media (radio and television) and public administration; other areas - legislation strengthening, justice, public order and national security, waste management, police, RHB protection, army and military facilities, security system, social services, managing water, nuclear power plants (Gačić, Proda, 2012, p. 163). After all, it should be noted that the critical infrastructures are related at the various levels of dysfunction and an infrastructure can easily affect the functionality of other infrastructures, and vice versa (Rajmohan, et al, 2012, p. 57).

2. PHENOMENOLOGY OF NATURAL DISASTERS

Natural disasters as adverse events to people, their material goods (critical infrastructure) and the environment, occur in different areas of the Earth (lithosphere, hydrosphere, atmosphere and biosphere), such as e.g. earthquakes, floods, epidemics, hurricanes, etc. (Degg, 1992, p. 37, p. 199). Depending on the nature of the process of formation, natural disasters can be divided into:

geophysical (earthquakes, volcanoes, tsunamis, landslides, bog); meteorological (tropical cyclones/hurricanes, thunderstorms, tornadoes, lightning, hailstorm, snowstorm, ice storm, blizzard, cold and hot waves, landslides, snow, fog and frosts), hydrological (flood, inundation), biological (epidemics and insect pests) (Edward, 2005, p. 58; Tobin, Montz, 2007, p. 98); and, extraterrestrial (meteors) (Edward, 2005, p. 58). Given the place of origin, natural disasters may be: originally from the atmosphere and hydrosphere (e.g., tropical cyclones, tornadoes), originally from the lithosphere (earthquakes, volcanic eruptions, tsunamis) and originally of the biosphere (forest fires, bacteria). Also, with regard to the "source of origin", they can be divided into: endogenous (earthquakes, volcanic eruptions), exogenous (floods and drought) and with anthropogenic (human) origin (floods caused by dam failure) (Bimal, 2011, p. 43).

The consequences of natural disasters for the people and their material goods (critical infrastructure) and the environment can have primary or secondary characters. Thus, for example, the primary consequences of the earthquake caused by tremors, are various forms of demolition (critical infrastructure), while the effects of the secondary character are associated with causing landslides, tsunamis and various fires. Thus thunderstorms may be accompanied by copious amounts of rain, which can cause sludge (mud), inundation and flooding.[1]

Table 1: Primary and secondary threats of natural disasters (Source: Bimal, 2011, p. 145)

Primary threats	**Secondary threats**
Earthquake	Landslides, tsunamis, fires, floods
Surge	Coastal flooding
Volcanic eruptions	Earthquakes, wildfires, floods
Forest fires	Landslides
Severe storms	Tornado, stream
Landslides	Tsunami
Extremely hot weather	Forest fires
Floods	Fires
Hurricanes/cyclones	Surge

Natural disasters increasingly threaten people and their property (critical infrastructure) day by day. In addition, the number of disasters recorded in the first half of the last century is only 6% of the total number of disasters that have occurred over a period of 105 years, 62% disaster in the last 100 years happened in the last 15 years of this period, with 80% disaster recorded over the past 100 years occurred in the last 25 years of this period, in any month in the last 100 years, there is an average of 12 disasters; disasters threaten all parts of the world, especially in poor countries; redistribution disaster on different continents and more than 60 % of disasters happen in Asia and Africa, with almost 50% of disasters have meteorological character, 30% have technological character, 12% geological and 8% have biological nature; the worst cases of earthquakes, floods and famines in the last 100 years occurred in China; the worst cases of landslides, avalanches and volcanic eruptions have occurred in Latin America... (Kourosh, Richard, 2008, p. 78).

1 The volcanic eruption of Mount St. Helena in 1980 caused earthquake, landslides, floods and fires.

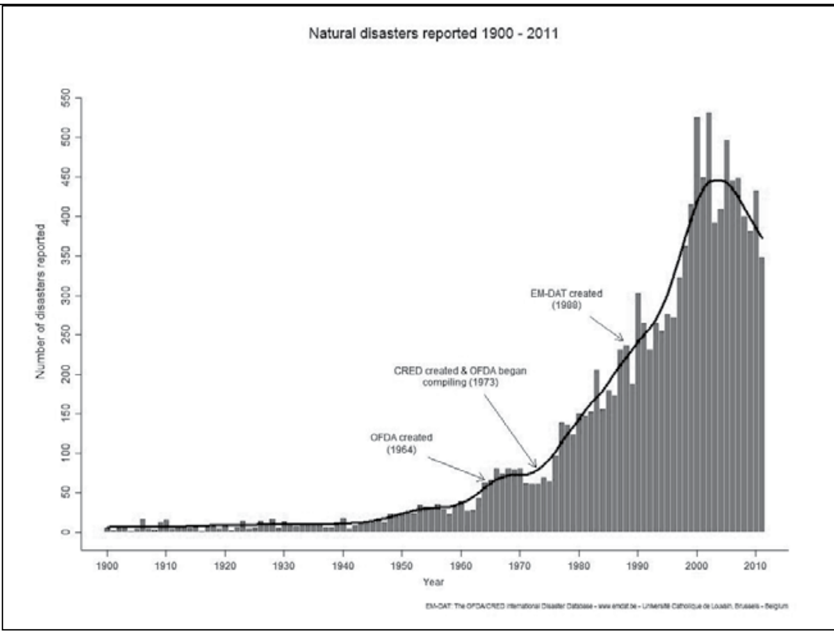

Chart 1: The trend of natural disasters from 1900 to 2011 (EM-DAT: The OFDA/CRED – International Disaster Database)

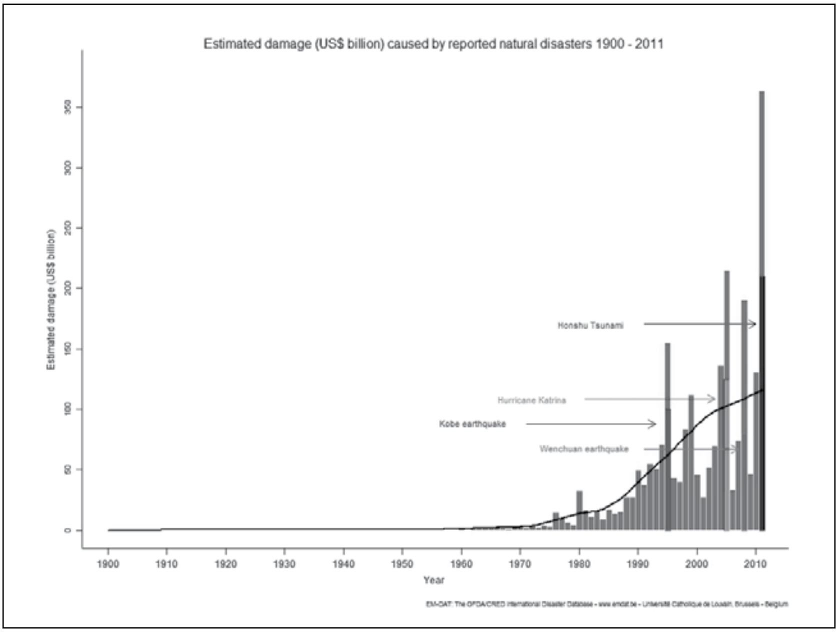

Chart 2: Estimated material damage caused by natural disasters, expressed in millions of U.S. dollars (EM-DAT: The OFDA/CRED – International Disaster Database)

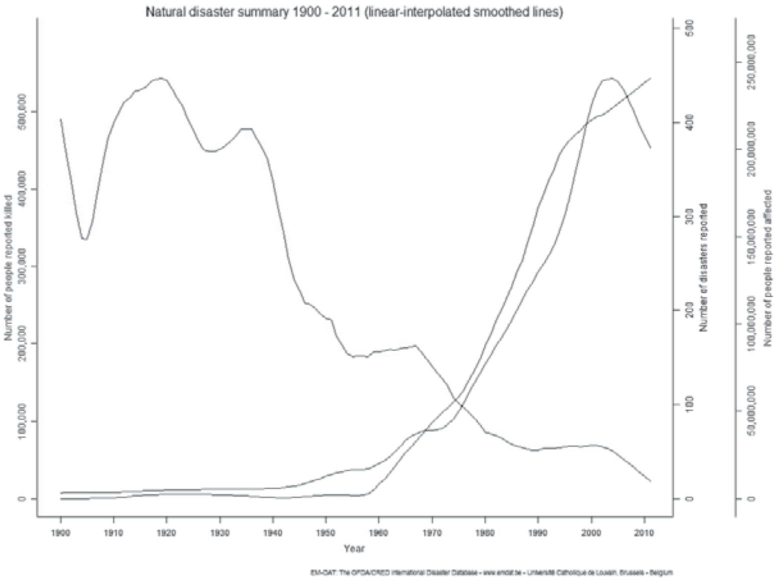

Chart 3 – The total number of natural disasters, casualties and material damage expressed in billions of U.S. dollars (EM-DAT: The OFDA/CRED – International Disaster Database)

3. CONSEQUENCES OF NATURAL DISASTERS ON CRITICAL INFRASTRUCTURE

The impacts of natural disasters on critical infrastructure can be seen through the understanding of the physical characteristics of natural disasters, that is, destructiveness that is determined by destructive force and possibility of propagation in the territory. The intensity of disasters is in strong correlation with the vulnerability of affected community (e.g., an earthquake of a certain severity will not cause the same damage to a rural village with crumbling earthen houses, and to a village with modern concrete multi-story buildings) (Cvetković, 2013). Consideration of the physical characteristics of natural disasters is important for mitigating the effects of various natural disasters (Tobin, Montz, 2007). There is a number of these characteristics:

1. 1.*Intensity,* that is, power or force of events. In general, the risk of large intensity is an enormous potential for causing destructive effects on people and their material goods, which is the critical infrastructure. The possibility of measuring the intensity of natural disasters allows the comparison of natural disasters in space and time. However, direct and absolute comparison is often not possible (Edward, 2005, p. 34).
2. 2. T*emporal distribution* is duration of natural disasters. It may take a few seconds (earthquake or landslide), hours or days (tornado or hurricane) or weeks or months (in case of flooding of the river), a few years (drought) (Hafiz, 2005). Accordingly, there will be a unequivocal correlation between the duration and the effects of natural disasters on critical infrastructure.

3. 3. F*requency* describes how often an event with certain intensity affects the area within a certain period of time (Bimal, 2011, p. 34). This can be expressed using terms such as "common", and "rare" or "return time", which is the time elapsed between two events of the same intensity. The frequency of hazardous events is assessed during careful examination and the analysis of historical records and the use of such information for predictive models.
4. 4. S*eason* - different studies have shown that certain natural disasters are not common in certain seasons (Preet, 2006). For example, the hot waves are not common during the month of December in Serbia, as it is unlikely that "blizzard" will infest Florida. Many types of natural disasters, especially hydro-atmospheric types are characterized by seasonal incidence (i.e., occur in certain seasons). Accordingly, certain types of critical infrastructure will suffer greater impacts due to natural disasters specific to different seasons;
5. 5. *Spatial distribution*, that is, risk distribution in the area where a disaster can happen (Bimal, 2011, p. 23) is an important parameter of natural disasters because areas are not subject to the same types of natural disasters.
6. 6. *Formation speed of a phenomenon* is the speed of a natural hazard turning into a natural disaster (Hafiz, 2005, p. 23). This can take place very quickly, as is the case with earthquakes, landslides, tornadoes and flash floods, or very slowly, as is the case with the drought. The first-mentioned type of disasters is called "creeping disaster", and the latter is called "sudden disaster". Sudden disasters typically cause bigger damage to critical infrastructure than creeping disasters, taking into account adaptation and coping mechanisms against natural disasters.

Considering all the facts presented so far, it can be safely concluded that natural disasters have great potential of direct/indirect threats to critical infrastructure. The vulnerability is the possibility of physical distortion and social disruption of societies and their larger subsystems by natural disasters (Bimal, 2011). There are two main types of vulnerability: <u>physical vulnerability</u>, as threats to physical structures and critical infrastructures, natural environment and is associated with economic losses (Committee on Disaster Research in the Social Sciences, 2006) and <u>social vulnerability</u>, as threats to well-being of the human population (e.g., death, injury, disruption of behaviour and functioning of the system) and is associated with non-economic losses.

3.1. Consequences of geophysical disasters on critical infrastructure

The earthquake is one of the most destructive geophysical disasters. It is a sudden shaking of the earth's crust (Bimal, 2011, p. 12). Earthquake's hit is sudden with almost no warning, making it impossible to predict. It damages the settlements, buildings, structures and infrastructure, particularly bridges, overpasses, railways, water towers, pipelines, the facilities for the production of electricity, and destabilizes the government, economy and social structure of the country (Edward, 2005). Subsequent earthquake's hits can cause heavy damage to already weakened structures. Secondary effects include fires, cracking dams and landslides that can block the land routes and waterways and cause flooding. It can cause damage to facilities with hazardous materials, resulting in leakage of chemicals. Also, there may be failure of communication facilities.

The consequences of earthquakes are diverse. There are a large number of casualties due to the poor design of buildings and critical infrastructure systems. Among the total number of persons who died in the earthquake, 95% of them lost their lives due to the demolition of buildings (Murray, 2012, p. 2). In addition, there is enormous damage in the public health system, transport, communications and water supply in the affected areas.

For example, the earthquake that hit Kobe in Japan in January, 1995, caused the following effects on critical infrastructure: 240,000 buildings were destroyed, 1.3 million people were left without water, 2.6 million people were left without electricity; 860,000 people were left without gas supply; 300,000 telephone devices were destroyed; highways and railways were destroyed; damage to the gas supply network was as follows: 26,459 medium-pressure cells were destroyed, it took 15 hours to stop the leak with a gas system and 85 days were spent on the reconstruction of gas pipeline network (Bimal, 2012, p. 119).

The earthquake that struck Kraljevo on 3 November 2010 seriously jeopardized the critical infrastructure. On that day the city was left with no heating and partially electricity, water was not recommended for drinking. Maternity hospital was flooded, in the "Studenica" Clinical Centre the operating rooms were not working, while shop shelves collapsed causing the supply of the population to be very difficult. Due to the earthquake, mobile telephony in Kraljevo was interrupted. In the village of Vitanovac, about 70% of 850 buildings collapsed. In Mataruska Spa several houses were damaged and cracked. In Kraljevo the streets were covered with pieces of glass, concrete and mortar, which disabled the normal flow of traffic. It is estimated that the total damage was around one million Euros (Valentine, 2011, p. 21).

3.2. Hydrological consequences of disasters on critical infrastructure

We are witnessing the catastrophic floods that cause huge damage, destroying villages, towns, farmland and critical infrastructures. Flood is one of the major threats to human community and has a significant impact on social and economic development. This deadly, harmful phenomenon kills thousands of people around the world annually thereby causing widespread damage. Even very small streams, gullies or small rivers are not harmless and can also cause flooding. Therefore, each country may be at risk of flooding (Blakie, et. al., 1994).

Flooding is uncontrolled flooding of land due to surface water outflow from natural and man-made waterways as a result of high water, punching or destruction of embankments, dams and other protection structures, as well as from flooding by inland waters in terms of abnormal weather conditions and rising groundwater and heavy rain, raising the levels of the lakes and the seas, due to the unusual strength of the waves and tides (Simon, George, 2000, p. 118).

Floods can occur gradually and can also take hours or even happen suddenly, without warning due to cracking of the embankment, spilling, heavy rain, etc. The flood greatly damages critical infrastructure. In addition, the structures such as houses, bridges and roads are damaged by incoming water. Landslides are triggered by incoming water, and boats and fishing nets may be damaged. Huge losses are in the form of human lives and livestock due to drowning. The lack of proper facilities for drinking water and the pollution of water (wells, groundwater, and drinking water) lead to the epidemics of diarrhoea, viral infection, malaria and many infectious diseases (COPO 2007). Flooding of large areas of agricultural land leads to the major losses of crops. This results in a lack of food, fodder and death of animals. Flooding may also affect the characteristics of the land, and it becomes arid due to erosion of topsoil or may become salty if it is flooded by sea water (Bimal, 2011). Depending on the strength and extent, the flood has undoubted potential to destroy bridges, damage traffic infrastructure, destroy communications systems, power supply, etc.

3.3. Consequences of meteorological disasters on critical infrastructure

Drought rarely causes structural damage. When meteorological drought starts turning into a hydrological drought, damage begins to appear first in agriculture that depends on the moisture in the soil. The irrigated areas are less influenced by drought comparing to the areas irrigated only by rain. However, the regions near rivers tend to continue a regular life, even when drought conditions prevail. In addition, the impact of drought slowly spreads to the social structures, as the availability of drinking water decreases, reducing the production of energy, groundwater pressure and food supplies, undermining the health of people and animals, increasing poverty, which causes the reduced quality of life and leads to social unrest and migration.

Hurricanes can cause serious damage to critical infrastructure. For example, hurricane Katrina hit different areas of the United States causing multiple damages. In fact, in Mississippi, Hurricane Katrina, coming up 25 to 30 feet, was removing vehicles and objects from the road. Hotels and buildings were significantly damaged and sometimes literally the whole community disappeared. In New Orleans, there was a flood due to the formation of holes in dams, and 80% of the city was under water up to 6 weeks. However, some parts of the city, particularly those near rivers, as French Quarter, were slightly flooded. Wind and rain caused significant damage to homes and offices. More than 1.3 million people were evacuated before Katrina made landfall, and about 800,000 people were relocated for a long period of time (Haddow, et al., 2011). Critical infrastructure, such as water, electricity, communications, schools and hospitals, was significantly damaged and dysfunctional in all the affected areas. Both state and private sectors suffered huge losses. The homes were damaged in the amount of $ 67 billion; operating assets suffered a loss of $ 20 billion, and the state assets in the amount of $ 3 billion.

4. INSTEAD OF A CONCLUSION: THE PROTECTION OF CRITICAL INFRASTRUCTURE AGAINST NATURAL DISASTERS

The protecting of critical infrastructure is recognized as the foundation of maintaining the functionality of the community in emergency situations such as natural disasters. The main goal of protecting critical infrastructure from the impact of natural disasters is to maintain the continuity of its operation (Hromada, Lucas, 2012). Reducing the impact of natural disasters on people and critical infrastructure includes interventions to prevent or reduce the possibility of physical treats and social disruption (Zhou, et al., 2010). However, there are two dominant types of reducing the impact of natural disasters. Structural reduction involves the design, construction, maintenance and renovation of physical structures and infrastructures to resist the physical forces and impacts of natural disasters. Non-structural reduction includes the efforts to reduce the exposure of human population, physical structures and infrastructures to terms of danger. Non-structural reduction approaches include legally adopted town planning measures that take into account the possible impact of the disasters; regulating development in high risk areas such as the sloping fields that are prone to landslides and the coastal zones as storm waves targets, and even in some cases the purchase and the relocation of communities or parts of the communities, which is a measure that is now used for areas that have experienced repeated flood losses (COPO, 2007, p. 123; Preet, 2006).

Examining the attributes and determinants of elasticity of facilities and critical infrastructure, researchers in Multidisciplinary Centre for Earthquake Engineering Research - MCEER, University at Buffalo, USA, have developed an R4 resistance frame: robustness, redundancy, resourcefulness and rapidity (Tierney and Bruneau, 2007). The first component of this framework refers to the *ability of the system*, system elements, as well as other units of analysis to withstand a given magnitude of the disaster without significant degradation or loss of function. Robustness reflects the inherent strength of the system. The lack of robustness may cause the system failure as happened with the breaking of the dike in New Orleans 2005 after Hurricane Katrina. The second R4 component - *redundancy* - refers to the extent to which elements of system are sustainable (i.e., able to meet the functional requirements if there is a significant impairment of functionality). Redundancy provides alternative options, choices and substitutions. The lack of these components prevents the proper response to natural disasters. A significant number of people in New Orleans were not able to get out in accordance with the mandatory evacuation before landslides during Hurricane Katrina, because public transport was unavailable (Harrington, et al., 2005). Component *resourcefulness* is associated with the capacity to diagnose the problem, the prioritization, and the adequate mobilization of resources for rapid recovery from the impact of natural disasters. Last R4 component is *rapidity*, and refers to the capacities to meet priorities and timely rehabilitate consequences and revitalize endangered values (Mileti, 1999).

In order to reduce the possibility of food shortages in the areas affected by the floods, it is necessary to plan the food storage on the high ground. Thus, the vulnerability of the system can be reduced by reducing dependence on one source of production or services; increasing the levels of portability in order to maximize the utilization of resources and the innovation of efficient and flexible systems that can withstand major disasters and reduce the need for reconstruction costs (COPO 2007). Warning against putting "all eggs in one basket" may be well applied here, because the system is less vulnerable when its resources of critical infrastructure are versatile and widely distributed (Bimal, 2011).

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