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# Seismic Progressive Collapse in a Steel Moment Frame Building: A New Aspect

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**Abstract**

Nowadays, large city structures are constructed such that minimal structural damage occurs after mild earthquakes that may hit them several times throughout their lifetime, and the buildings stay functioning. Confined explosions, such as the explosion of gas pipelines situated inside structures, are always a threat to the safety and functioning of buildings after earthquakes. Despite its significance, this thread receives less consideration in architectural design. The connection between the danger of collapse and the building's dependability is shown in this research using a probabilistic method. The impact of a mild earthquake on a four-story steel structure with unique moment frames, as well as the likelihood of sequence explosions of gas pipelines at likely ground-floor sites, were studied both as case study. The damaged building's resistance ability to a moderate earthquake followed by an explosion against gradual collapse was then assessed. Finally, the likelihood of progressive collapse and the structure's dependability were estimated. The explosive weight ranges for buildings have also been calculated for various situations, such as safety and small damage, and the building's collapse risk and dependability have been evaluated using a probabilistic approach, with the findings explained.

***Keywords:*** *Steel Moment Frames, Progressive Collapse, Plastic Design, Virtual Work Method.*

## Introduction

Damage sustained by buildings in the past earthquakes indicates the necessity of logical methods to predict the collapse probability and probable damage of existing buildings in future earthquakes. “The philosophy of designing buildings against earthquake in the current codes is prohibition of structural damage and minimization of non-structural damage under moderate ground motion happening many times during their lifespan. Despite regarding the provisions in seismic design of buildings, the incidence of such damage and the lack of capability of exploiting them are probable. Among the most important threats the earthquake may cause for buildings is the limited explosion in the gas system of the engine plant of the building after the earthquake due to mechanical damage of the gas piping system and its connections. The finite blasts are the explosions that happen in closed spaces like tanks, procedural installations, pipes, closed rooms and underground equipment. One of the factors causing damage of gas pipes is lack of providing flexibility for them. From the other view, corrosion, leakage, unsuitable welding and collision of the pipes are among the factors causing damage. The explosion of gas–pipeline has occurred in past earthquakes but less attention is paid to it. In this study, the risk of the progressive collapse of buildings under moderate earthquakes followed by gas–pipe explosions is evaluated.

When one or more structural members of the building are destroyed suddenly due to the explosion, each load distribution may cause fracture of other structural elements one after another and the building may collapse progressively. Among the first researchers studying the progressive collapse are [19] who presented various approaches to mitigate this issue. The current procedure for designing the structure against the explosion is designing against local failure of elements in first step and then using tactful measures to prevent spread of damage to other elements in next step. Nowadays, evaluation techniques and risk management procedures for decreasing vulnerability derived from natural disasters and man-made hazards have been paid attention a lot. Stewart et al. [28] have studied evaluation of the possible dangers arisen from explosion terror-stricken damage to infrastructures. In this review, the problems about the risk assessment including the risk transfer concept as well as comparisons with natural hazards have

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been discussed. Asprone et al. [5] have presented a probabilistic model to evaluate the hazardous risk along with limit state of collapse for a reinforced concrete building exposed to explosive threats located in a seismic site. Parisi and Augenti [23] assessed the performance of seismic resistant RC frame structures designed according to Eurocode 8 code, under blast loadings. They developed the intended blast scenarios in accordance with structural site quality and the amount of explosives required. Then, to evaluate the robustness of the building, they performed a pushdown analysis. Fu [13] advanced a new method to estimate a tall building's response to blast loadings. He finally offered a comparison between his proposed method and alternative path method (APM). In this study, by presenting a probabilistic approach, the relationship to determine the risk of collapse and reliability of building is presented. And as a case study, effect of the moderate earthquake on a four-story steel building with special moment frames and probability of sequence explosion of gas pipes in probable locations in ground floor have been investigated. On the other side, one can observe that in most moderate earthquakes along with critical earthquake load, gas explosive can increase the damages subjected to a structure. This factor highlights the significance of performing the current study so that one can evaluate the collapse rate of the structure with an appropriate method under such condition and also obtain an acceptable and correct assessment of structures subjected to these two critical loads.

## Literature Review

Explosion is the sudden release of energy that can be as gaseous combustion, nuclear explosion or variety of bombs. The TNT unit is usually used as a reference to determine the explosion power. When an explosion wave hits a building, the building is under the load derived from the tension and pressure forces of the explosion wave. Among the main characteristics of an explosion which impose force on the structure, the random explosion situation, dynamic and transitory and the short time of action (between few milliseconds to few seconds) can be pointed. Each blast load is determined by three parameters: the wave shape, the peak overpressure (Pso) and time duration (td). Based on the explosion origin, blast waves are divided into two shapes: the impact wave and the pressure wave. The impact wave is resulted from explosion of solid explosives in which the gas pressure formed by explosive propagates from explosion source and increases to the base pressure (Pso), then decreases to the environmental pressure. This stage is referred as positive phase. As a result of the wave propagation, the gases derived from explosion are cooled and their pressure is reached to a negligible amount lower than the atmosphere pressure. Due to this pressure difference, the current direction gets reversed towards the explosion center. The result of this action is decrease in the pressure or stuck that is called negative phase" [1, 15]. The pressure of the negative phase is relatively small and gradual so it is conservatively ignored in designing the resistant buildings against explosion (Fig. 1)

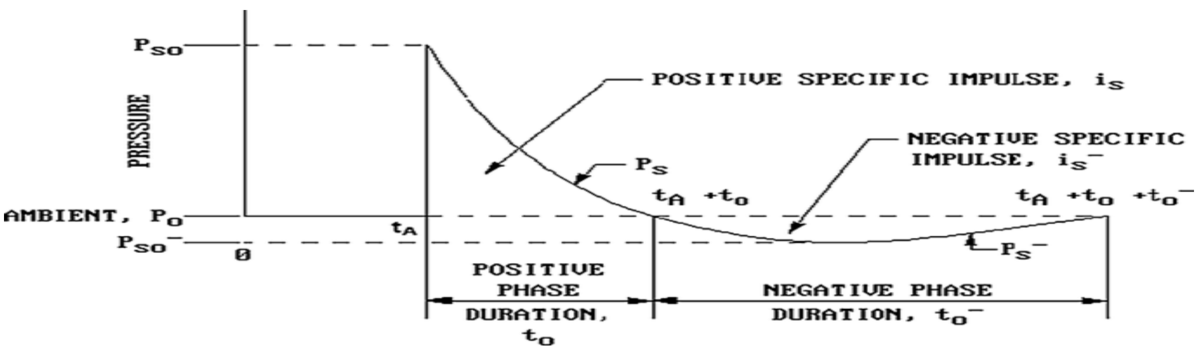


**Figure 1: Positive Specific Impulse**

"Since the early development of structural design against progressive collapse, there have been many improvements in the provisions in codes and standards to provide guidance, design requirements and more realistic and explicit procedures for the prevention of progressive collapse in structures. Presented below is an overview of current progressive collapse provisions and guidelines in some commonly adopted codes and standards for structural design in NorthAmerica.

The National Building Code of Canada 2005 (NBCC 2005) [10] and American Concrete Institute's Building Code Requirements for Structural Concrete 2008 (ACI 318-08) [11] rely on structural integrity requirements to prevent progressive collapse of structures. This is based on the assumption that improving redundancy and ductility by good detailing in reinforcements can help to localize the damage so

## Plastic and its Variety

Plastics are low-budget, lightweight, strong, durable, corrosion-resistant materials, with high thermal and electrical insulation properties (Andrade et al., 2016). The diversity of polymers and the versatility of their properties are used to make a vast array of products that bring medical and technological advances, energy savings and numerous other societal goodness (Thompson et al., 2009). As a consequence, the production of plastics has increased substantially over the last 60 years from around 0.5 million tonnes in 1950 to over 260 million tonnes at present (Saxena and Singh, 2013). Properties of plastic Plastic have many great characteristics which view versatility, low weight, hardness, and resistant to chemicals, water and impact and all these make plastic is one of the most disposable materials in the modern world. It makes up much of the street side litter in urban and rural areas. It is rapidly filling up landfills as choking water bodies (Jalaluddin, 2017). Plastic bottles make up approximately 11% of the content landfills, causing serious environmental consequences. Due to the outcome, some of the plastic facts are: 1. There's an idea that 100 million ton of plastic is produced every year around the globe. 2. He average European throws away 36 kg. of plastics each year. 3. Plastics packaging totals 42% of total consumption and every year little of this is recycled. Reported to ENSO Bottles, in the 1960's plastic bottle production has been negligible but over the years there was an alarming increase in bottles produced and sold but the rate of recycling is still very low. 1. Plastics packaging totals 42% of total consumption and every year little of this is recycled. According to ENSO Bottles, in the 1960's plastic bottle production has been negligible but over the years there was an alarming increase in bottles produced and sold but the rate of recycling is still very low. 2. More than 20,000 plastic bottles are needed to acquire one ton of plastic. Disadvantages of plastic: i. Plastic is nonrenewable source of energy. ii. It takes millions of years to decompose naturally. iii. Converting raw plastic into useful material is not an easy process. iv. Plastic is difficult to recycle (Andersen et al., 2006). Plastics also present many public health benefits. They facilitate clean drinking water supplies and enable medical devices orbiting through surgical equipment, drips, aseptic medical packaging and blister packs for pills. They provide packaging that reduces food wastage, for instance in the use of modified atmosphere packaging that extended the life of meat and vegetables (Andrady and Neal, 2009). Owing to their light weight, plastics reduce transportation costs and therefore, atmospheric carbon dioxide emissions. Public and private transportation vehicles can now contain up to 20% plastics typically as parcel shelves, door liners, steering wheels, electrics and electronics, and recent aircraft such as the Boeing Dreamliners is designed from up to 50% plastics (Shah et al., 2008). Plastics can also be used to improve the performance and trim the costs of building materials; examples of this include lightweight fixings, window and door frames, fixtures and insulation materials. Plastics deliver unparalleled design versatility over a wide range of operating temperatures. They have a high strength-to-weight ratio, stiffness and toughness, ductility, corrosion resistance, bio-inertness, high thermal/electrical insulation, non-toxicity and outstanding durability at a relatively low lifetime cost compared with competing materials; hence plastics are very resource efficient (Chatterjee and Sharma, 2019). Impact of plastic on marine environment Plastics are a class of artificial organic polymers composed of long, chain-like molecules with a high average molecular weight. Many common classes of plastics are composed of hydrocarbons that are typically, but not ever, derived from fossil fuel feed stocks. During the transition from resin to product, a wide variety of additives-including fillers, plasticizes, flame retardants, UV and thermal stabilizers, and antimicrobial and coloring agents-may be added to the resin to heighten the plastic's performance and appearance. Talking about micro plastics, these tiny (micro) plastic fragments are persistent in the marine ecosystem and due to their micron sized molecule nature, these fragments are mistaken as food and ingested by a range of marine biota which includes corals, phytoplankton, zooplankton, sea urchins, lobsters, fish etc. and ultimately get transferred to higher tropic level. The impact of micro plastic on marine biota is an issue of concern as it leads to the entanglement and ingestion which can be fatal to marine life. The micro plastic fragments mainly arrive from terrestrial source and thus coastal ecosystems which incorporate of coral reefs are in great threat due to micro plastic pollution. The result is a class of materials that have extremely versatile and desirable properties (including strength, durability, light weight, thermal and electrical insulation, and barrier capabilities) and can take many variety (such as adhesives, foams, fibers, and rigid or flexible solids, including films. In the intervening decades, hundreds of publications have documented encounters between

marine debris and nearly 700 species of marine wildlife. For particular species or populations, documented encounters occur frequently. For example, 95% of 1,295 beached seabird carcasses in the North Sea contained plastic in their stomachs, and 83% of 626 North Atlantic right whales examined in 29 years of sighting photographs had evidence of at least one entanglement in rope or netting. It was reported that 85% of publications about marine debris encounters described incidences of entanglement by or ingestion of debris, with at least 17% of affected species categorized as near threatened to critically endangered on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species. The vast majority (92%) of the debris in reported encounters with individual organisms was plastic. Entanglement has now been reported for 344 species, including 100% of marine turtles, 67% of seals, 31% of whales, and 25% of seabirds, as well as 89 species of fish and 92 species of invertebrates. Animals that consume plastic debris may also be at risk of contamination by chemicals associated with plastics that are incorporated during manufacture or that accumulate from contaminated environmental matrices such as sediment or seawater. Many of these substances are known to be Persistent, Bio accumulative, and Toxic (PBT), with at least 78% of the priority pollutants identified by the US EPA known to be associated with plastic marine debris (Lin, 2016). PBT substances are typically hydrophobic and therefore readily absorb out of seawater onto other hydrophobic substances, such as sediment, organic matter, and now plastic. In fact, because of their strong attraction to PBT substances, some plastics are utilized as passive sampling devices to measure chemical contaminants in a variety of environmental matrices (Hiremath et al., 2014). Uses of plastic in Construction Fibers have been used to reinforce brittle materials since ancient times. The use of straw to strengthen bricks and stabilizes their dimensional instability has been practiced for centuries. Fiber reinforced concrete (F.R.C) is relatively new construction material developed through extensive research and development work during last three decades (Patil et al., 2016). It has found a wide range of practical applications and has proved as reliable construction material having superior performance as compared to conventional concrete. Incorporation of various fibers in concrete has been found to Bhupender Kumaret al. 54 improve several of its properties like tensile strength, cracking resistance, impacts wears resistance, ductility and fatigue resistance, due to which FRC is now being used in structures such as airport pavement, bridges decks, machine foundations, blast resistance structure, sea-protective structures etc. It was concluded that reusing the plastic bottles as the building materials can have substantial effects on saving the building embodied energy by using them instead of bricks in walls and reducing the CO emission in manufacturing the 2 cement by reducing the percentage of cement used. It is counted as one of the foundation's green project and has caught the attention of the architecture and construction industry. Generally the bottle houses are bio climatic in design, which means that when it is cold outside is warm inside and when it is warm it is cold inside. Constructing a house by plastic bottles used for the walls, joist ceiling and concrete column offers us 45% diminution in the final cost. Separation of various components of cost shows that the use of local manpower in making bottle panels can lead to cost reduction up to 75% compared to building the walls using the brick and concrete block (Shoubi and Barough, 2013). Plastic fiber reinforced concrete (PFRC) is a type of special concrete in which various types of plastics are added or replaced with the constituents of concrete. This has been done in order to reduce the disposal of plastics and for effective utilization of waste plastics that are hazardous to environment. This study attempts to give a contribution to the effective use of domestic wastes (plastics) in concrete as fibers in order to prevent the environmental strains caused by them, also to limit the consumption of natural resources (Ramadevi and Manju, 2012). The experimental studies on a M20 mix with addition of polythene fibers (domestic waste plastics) at a dosage of 0.5%. The cube compressible strength of concrete increases to an extent of 0.68% and 5.12% in 7 and 28 days, respectively. The cylinder compressible strength of concrete increases to an extent of 3.84% in 28 days". The split tensile strength of concrete increases to an extent of 1.63% in 28 days. Katte et al. studied the partial replacement of natural sand by plastics with different percentage 0% to 50%. In concrete, Natural sand can be replaced with plastic waste by 10% to 20% to achieve green concrete. "Sand can also be replaced up to 30% in the members of building which do not carry high load (Ananthi et al., 2017). Future Prospectus and conclusion Plastic, even though being something that's destroying the biomes, is something that can be of precious use in the field of construction if the waste is processed and used and then recycled
judiciously as per needs. The production, use and waste generation of plastic products is expected to increase in the future and thus it is urgent to increase the re-use and recycling of plastic waste for transitioning to a resource

efficient circular economy in Sweden. For increasing plastic recycling, there is a number of per-conditions that need to be met, summarized in the following: 1. Appropriately established schemes for the separate collection of plastic waste. 2. Steady supply of plastic waste in
adequately high volumes. 3. Well-functioning markets for plastic waste with clear signals of secondary raw material demand. 4. Quality guarantees by the recycling industry for uptake in plastic manufacturing processes. To achieve this, recyclable plastic waste would have to be gradually phased out from incineration facilities for energy production (Law, 2017). This would be a great challenge, as incineration plants contribute significantly to the heating needs of municipalities. However, prohibiting the incineration of recyclable plastic waste would lift one of the major barriers of plastic recycling, the supply of waste plastic. It could provide a large quantity of waste of variable quality. Therefore, a ban on incineration would necessarily need complementary measures of sorting and recycling technology development, as well as capacity expansion (Government of Sweden, 2015). This highlights the need for more research into controlling biodegradability, taking into account different applications and the need for infrastructure to deal with biodegradable plastics at the end of their life. Obviously, we don't want our planes biodegrading during their 20 years of service, but one-use water bottles should break down within a short time after use. The planet doesn't have to become a toxic rubbish dump that it will not propagate to other members, and thus the overall stability of the structure can still be satisfied.

American Society of Civil Engineers' Minimum Design Loads for Buildings and Other Structures 2005 (ASCE/SEI 7-05) [12] specifies two alternative design approaches for increasing resistance against progressive collapse: direct design and indirect design. The direct design approach basically consi- ders resistance to progressive collapse explicitly during the design process by either the alternative load path method or specific local resistance method. The alternative load path method allows local failure to occur but the progressive collapse mechanism is averted or bridged over with alternate load paths to distribute the load from the missing member to other redundant members so that the effect of the damage can be absorbed. The specific local resistance method does not allow local failure to occur by providing sufficient strength on the "key" element to resist the failure of a structural member. While the direct design approach offers a more explicit design solution, the indirect design method takes a different methodology approach. It considers resistance to progressive collapse implicitly during the design process through the provisions of minimum levels of strength, continuity, and ductility. It is also stated that structures can be designed to sustain or minimize the occurrence of progressive collapse by limiting the effects of a local collapse from spreading out to other members except for special protective structures where extra protection is needed. On the other hand, ASCE/SEI 7-05 also removed the minimum base shear requirement for building with spectral response acceleration parameter at a period of 1 s (S1) less than 0.6 g. This change of minimum base shear requirement for long-period buildings compared to its predecessor tends to increase the risk of progressive collapse [13].

General Services Administration (GSA) Guidelines

It states that redundancy, detailing to provide structural integrity and ductility, and capacity for resisting load reversal need to be considered in the design process to make the structure more robust and thus enhance its resistance against progressive collapse. It stipulates an analysis procedure of removing vertical load bearing elements to assess the potential of progressive collapse to occur in a structure. The guideline also gives requirement on maximum allowable collapse area that can occur if one vertical member collapses. Figure 2 shows the example of the maximum allowable collapse area if an exterior or interior column fails.

## Progressive Collapse Analyses

A progressive collapse analysis is needed to determine the capability of a structure to resist abnormal loadings. There are several methods that can be used: linear static, nonlinear static, linear dynamic, and nonlinear dynamic. Each of them has some advantages and disadvantages. A brief summary of different analysis methods is presented herein. Further details and discussions of the four progressive collapse analysis methodologies can be found in the paper by Marjanishvili.

- Linear static analysis is the fastest and easiest to perform but it does not consider the dynamic effect and any nonlinearity effects due to material and geometric nonlinearity. Also, this analysis is only applicable to analysis of structures with simple and regular configuration.

- Nonlinear static analysis takes into account the effects of material and geometric nonlinearity but does not consider the dynamic effect directly in the analysis. The procedure is relatively simple yet gives sufficient important information about the behaviour of a structure.

- Linear dynamic analysis includes the dynamic behaviour of the structural response but it does not consider the effects of material and geometric nonlinearity. It may not give good results if the structure exhibited large plastic deformations.

• Nonlinear dynamic analysis gives the most exact results and includes both material and geometric nonlinearity and dynamic effects, but the practice is rigorous and time consuming. This method is often used as a verification to supplement results obtained from other methods.

When a structure undergoes progressive collapse, the response of the structure is affected by dynamic effects [18, 19]. This requires the dynamic behaviour of a structure to be taken into account in the progressive collapse analysis. It is also expected that nonlinear structural behaviour can significantly affect the progressive collapse behaviour of a structure since before reaching the collapse condition a structure and its member components must have exceeded its elastic limits. Considering these two observations, it can be concluded that the nonlinear static analysis and nonlinear dynamic analysis are the two most appropriate methods for evaluation of progressive collapse behaviour of structures among the available analysis methodologies still provide valuable insights on the behaviour of the analyzed structure and the results tend to be conservative in most cases. The attractiveness of this method is its simplicity In nonlinear static analysis, dynamic effects in the responses are not considered directly. Despite this limitation, experiences have shown that the results obtained by nonlinear static analysis can stability of structural systems [20]. Nonlinear static analysis has also proven to give good estimates to seismic demands of structures. Therefore, nonlinear static analysis procedure is a valuable alternative method to the more rigorous nonlinear dynamic method for analysis of compared to nonlinear dynamic analysis approach. Studies have shown that nonlinear static analysis methods can give good approximations of deformation demands, identify the strength discontinuities, and assess global progressive collapse behaviour of structures. Using the nonlinear static analysis procedure, a capacity curve of a structure can be generated by pushover analysis. A capacity curve provides insight whether a structure has adequate capacity to resist the loading condition or not. During progressive collapse, dynamic properties of a structure change after failure of one or more members in the system. Therefore to capture the progression of the collapse mechanism, it may require multiple pushover analyses if the analysis tool employed in the simulation does not specially model and capture the progressive changes in structural properties and behaviour of the system. For seismic progressive collapse evaluation, the analysis procedure should take into account the effects of lateral seismic forces in conjunction with those from gravity loads. It requires an analysis tool that can capture the structural responses from initial localized failure of individual structural elements or components, to partial collapse, collapse and post- collapse behaviour of the structure. Current progressive collapse analysis procedures that only account for gravity load effect may not have the capabilities to model and capture the total effects of progressive collapse of structures due to overloading during earthquakes. In addition, falling debris from collapsed members may result in significant impact loading to other members in the remaining system, which also needs to be considered in the analysis.

## Conclusion

A brief overview of progressive collapse phenomenon in structures has been presented. The approaches of several code and standard provisions on preventing progressive collapse have been discussed. The merits and limitations of available analysis methods for assessment of progressive collapse of structures have been summarized. The significance of seismic load effects in progressive collapse behaviour of structures has also been discussed”. It is concluded that seismic progressive collapse of structures can be analysed by modifying the current analysis procedures.

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