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SUSTAINABLE DEVELOPMENT AND MAJOR INDUSTRIAL ACCIDENTS: THE BENEFICIAL ROLE OF RISK-ORIENTED STRUCTURAL ENGINEERING

Egidijus Rytas Vaidogas[1], Virmantas Juocevičius[2]

Dept of Occupational Safety and Fire Protection, Vilnius Gediminas Technical University, Sauletekio al. 11, LT 10223, Vilnius, Lithuania,
e-mail: erv@st.vgtu.lt[1]; virmantas.juocevicius@conserela.lt[2]

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Abstract. Sustainable development can be restricted by major accidents which occur in hazardous industries. Almost every major accident may have negative influence on each of the three constituents of the sustainable development: social, environmental and economic part. A characteristic feature of the most of major accidents is severe damage to the structural systems built inside and outside of the industrial facility in which the accident happens. To avoid such accidents or at least to reduce their consequences, structural systems should be designed using a risk-based approach. On the level of detailed structural design, a formal measure of risk should be introduced and applied to express the effectiveness of the structural solution in terms of accident mitigation and minimization of potential consequences. The structural design should involve the consideration of possible accident scenarios and positive or negative contribution of structures and structural failures to the escalation or de-escalation of the accident. This can be done by applying the risk-oriented structural design. A well-established methodological framework for such a design is provided by the quantitative risk assessment. A consequent application of a risk-based approach can be one of the risk management tools which will reduce the number of major accidents and thus their negative influence on sustainable development.

Keywords: sustainable development, industrial accident, risk, mechanical damage, consequences, fire, explosion, collision.

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1. Introduction

The term "sustainable development" has been defined best by Brundtland Commision as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Sustainable development does not focus solely on environmental issues. The United Nations 2005 World Summit Outcome Document (WSOD 2005) refers to the "independent and mutually reinforcing pillar" of sustainable development as economic development, social development, and environmental protection (Fig. 1).

Sustainable development is essentially about improving quality of life in a way that can be sustained, economically and environmentally, over a long term supported by the institutional structure of the country. The process of sustainable development can be restricted or interrupted by an industrial accident which can be caused either by natural phenomenon or human activities. The degree of impact of a particular accident may depend on its character and magnitude. Most industries of European Union (EU), in which major accidents may occur, are regulated by the Seveso 2 directive (Christou *et al.* 1998, Babinec *et al.* 2005, Vince 2007, Mahony *et al.* 2008, Rutkauskas 2008). Clearly, this document does not cover every sector of industry; however, the principle implemented in the Seveso 2 directive are applicable throughout the industry. Despite all regulations and efforts to reduce the number of accidents, they are still present in the everyday industrial activities and happen with unacceptable regularity (e.g., Gowland 2007).

Industrial accidents on the nation-wide scale and on the scale of EU are not rare events (Gheno and Lee 2006, Hola 2007). For example, according to European Statistics in 2001 the industry of EU-15 countries had to sustain 7,6 million accidents in which 4900 fatalities occurred (Eurostat 2004). The MARS database records that approximately 30 major accidents

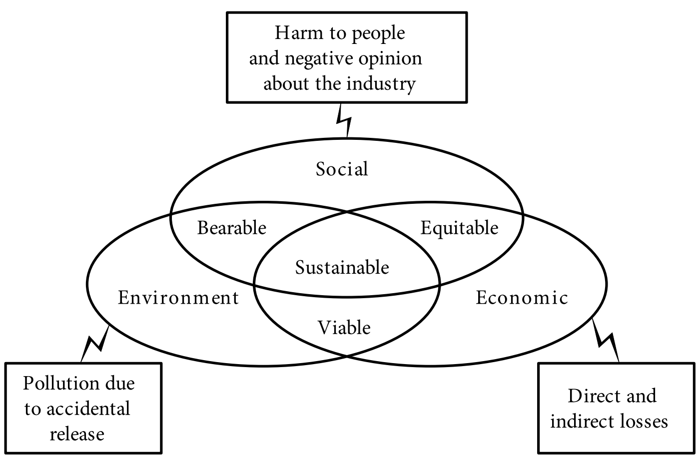

Fig. 1. Three constituent parts of sustainable development (in ovals) and restricting influence of industrial accidents on this process (in rectangles)

happen each year within the industry sectors covered by the Seveso 2 directive (ETPIS 2007). These accidents are not major contributors to the overall statistics but have a major impact on industry and society and thus on sustainable development (Fig. 1).

The present paper is an attempt to address the problem of sustainability from the standpoint of risk-oriented structural engineering. It is stated that the negative influence of major industrial accidents on the sustainable development can be reduced to a certain degree by applying structural design solutions which mitigate the effects of an accident. The attention is focused on the major accidents which are particularly severe and can cause failures of such robust objects as structures. To avoid consequences of these failures or reduce them, a risk-based approach to the structural design should be applied (Vaidogas 2005, 2007a; Vaidogas and Juocevicius 2007; Baker *et al.* 2008; von Radowitz *et al.* 2008). The paper takes the look at how to "marry" the formal framework of risk assessment and management with the structural design. In particular, it is considered how to integrate the event of a potential structural failure during an accident into the methodological framework quantitative risk assessment (QRA).

2. Industrial accidents and sustainable development

Despite all measures taken in the hazardous industries, accidents re-occur with unacceptable regularity (e.g., Hadad *et al.* 2007). Most of them pose relatively low consequences which can have little influence on the process of sustainable development. For example, 18 000 accidents were reported in all industries in the FACTS database (Sonnemans *et al.* 2006). From these accidents 3916 accidents happened in petro-chemical industries. Of those 585 happened between 1995 and 2000, only 90 of these accidents were rated as 4-star or 5-star accidents, which also can be classified as major accidents. Losses due to property damage and business interruption caused by major accidents may amount to very impressive figures (Table 1). However, such accidents pose also indirect consequences. These may be of legal and social nature and may affect the whole industry "touched" by major accidents. For instance, in 1980s US chemical industry has almost completely stopped all investments in new manufacturing plants due to legal overregulation which was in part a consequence of major chemical accidents (Kumamoto and Henley 1996, p. 579). Monetary and non-monetary consequences of major accidents should be of concern for those who are interested in continuation of sustainable development.

The major accident, which occurred at Toulouse on 21st September 2001, killed 21 people on the site, 9 people off-site and injured 2242 people. 27 000 homes and 1300 companies suffered significant damage. 5000 people needed treatment for acute stress. The economic cost exceeded €1500 million. This accident involved considerable damage to structures and large objects traditionally assigned to mechanical engineering (Marlair, Kordek 2005; Dechy *et al.* 2001).

The 2001 Humber Refinery explosion was a major incident at the Conoco-owned Humber Refinery at South Killingholme in North Lincolnshire. A large explosion occurred when 170 tonnes of highly flammable Liquefied Petroleum Gas was released in the Saturate Gas Plant area of the site on 17th April 2001. Due to the failure of a pipe a gas cloud developed

Table 1. The cost of 14 accidents experienced world-wide in 1977–1992 (Fewtrell and Hirst 1998)

Location	Date	Cost (US$ 1996)	Includes business interruption losses?
Pasadena, Texas, US	23/10/89	$1,456 million	Yes
La Mede, France	11/09/92	$458 million	Yes
Pampa, Texas, US	14/11/87	$396 million	Yes
Antwerp, Belgium	07/03/89	$356 million	Yes
Thessaloniki, Greece	24/02/86	$300 million	No*
Norko, Louisiana, US	05/05/88	$293 million	No*
Sweeny, Texas, US	04/13/91	$264 million	Yes
Romeoville, Illinois, US	23/07/84	$241 million	No*
Port Neal, Iowa, US	13/12/84	$182 million	Yes
Sodegaura, Japan	16/10/92	$172 million	No*
Seadrift, Texas, US	02/12/91	$172 million	Yes
Umm Said, Qatar	03/04/77	$156 million	Note*
Shuaiba, Kuwait	20/08/81	$148 million	No*
Sterlington, Louisiana, US	05/01/91	$148 million	Yes

Fewtrell and Hirst (1998) quote the information that business interruption losses reported in UK in 1997 were on average 2,7 times property damage losses; however, there were wide variations between individual cases.

Fig. 2. Explosive damage to the building with portal steel frames (at the middle-left side of the picture; BP Texas City explosion March 2005) (CSHIB 2005)

Fig. 3. Explosive damage to technological piping (top-right side of the picture; BP Texas City explosion March 2005) (CSHIB 2005)

which then ignited causing a massive explosion. As fire burned it caused failures of other pipework resulting in further fires. Two people were injured. Damage was caused to the nearby villages of North and South Killingholme and Immingham – mainly doors were blown from their hinges and windows blown in. ConocoPhillips was investigated and subsequently fined £895 000 and ordered to pay £218 854 costs by Health and Safety Executive for failing to effectively monitor the degradation of the refinery's pipework (HSE 2001).

On March 23, 2005, a series of explosions and fires at BP Texas City refinery killed 15 people and injured 170. Extensive mechanical damage to process equipment was caused during this accident (Figs 2 and 3). In the aftermath of the accident a group of 39 UK public sector pension fund 'turned the screw' on BP over the oil major's safety failures. The local Authority Pension Fund Forum, whose members have £70 billion of assets under management, have called on BP to improve corporate governance procedures (Gowland 2007).

Major industrial accidents occurring in a particular industry may lead to changes in regulatory legislation and attitude of society towards the industry (Casal 2008). These changes may cause an increase of safety culture in the industry and so be a good influence on its sustainability. Establishing a quantitative relation between the process of sustainable development and industrial accidents is a very difficult task. However, it is natural to expect that attempts to significantly minimise their number or eliminate them completely may result in the increase of sustainability of the industry.

There exists a wide variety of managerial and technological means which allow reduction and elimination of major accidents (e.g., ETPIS 2006). The three aforementioned disasters show that the most severe industrial accidents involve damage to structures. However, structures can be the “last line of defence” against accidents. Properly designed structures may be capable to sustain physical phenomena induced during the accidents or to fail in an expected manner and so mitigate the progression of hazardous processes. Therefore it is reasonable to anticipate that a design of structures for potential accidents will be most successful if it is included in the context of managing risks posed by major accidents.

3. Risk of industrial accidents: a brief view from the standpoint of structural engineering

The design of an industrial object will always include the design of its structural components. In case where QRA is carried out for such an object, the risk assessment should consider potential damage to structural parts of the object. This damage can be incorporated into the general framework of QRA (Vaidogas 2007a,b; Kala 2008).

Many business activities generate risk of major accidents. Consistent methodological means for expressing and estimating this risk are provided by QRA. A principal purpose of QRA is a derivation of risk profiles (measures) for a given activity. An industrial accident can be a complex phenomenon as regards its consequences (damage to property, nature, and harm to people). The consequences will cover all types of potential damage and so may include structural failures. A systematic prediction of these consequences is expressed in the standard form of risk widely used for QRA (e.g., Kumamoto and Henley 1996):

$$\text{Risk} = \{(L_i, C_i, \mathbf{S}_i), i = 1, 2, \dots, n\}, \tag{1}$$

where L_i is the likelihood (usually frequency or annual probability) of the consequences C_i; $\boldsymbol{S}_i$ is the vector expressing the significance (magnitude) of the consequences. The consequences C_i are outcomes or effects of failure as a logical result or conclusion, for instance, gas cloud, fire, explosion, injuries, deaths, environment damages, damage to the facility (Ayyub 2003, Cheng *et al.* 2008, Haque 2008). The likelihood L_i is expressed in various ways depending on the context, in which the accident may take place (Table 2).

Failure significance $\boldsymbol{S}_i$ is the quality, condition, strictness, impact, harshness, gravity, or intensity of the failure consequences. The amount of damage that is (or may be) inflicted by a loss or catastrophe is a measure of significance. The significance cannot be assessed with certainty, but it is preferable to try to define it in monetary terms. The significance $\boldsymbol{S}_i$ can be spread as follows (Kumamoto and Henley 1996, Ayyub 2003):

$$\mathbf{S}_i = \begin{cases} S_{i1} = \text{direct monetary losses} \\ S_{i2} = \text{number of fatalities and injuries} \\ S_{i3} = \text{indirect (consequential) monetary losses} \\ S_{i4} = \text{lost time} \\ S_{i5} = \text{longevity loss} \end{cases} \tag{2}$$

Table 2. Specific form of the likelihood L_i (Kumamoto and Henley 1996; Vaidogas 2003)

Measure	Unit	Example of hazardous event or activity
Probability	Per action (involving an accidental action hazard)	Transportation of untypically heavy load through the bridge; the burn-in phase of hazardous system which can fail by inducing accidental action
Frequency	Per unit time or during lifetime (of operating facility (carrying out an activity) involving accidental action hazard)	Rear occurrences of adverse natural phenomena imposing excessively high loads; catastrophic accident capable of causing devastating consequences and making recovery of system un-probable (uneconomical)
Probability at the time t	Per action (taken repeatedly with a changing accidental action hazard)	Transportation of tank with flammable liquid through the tunnel; emergency landing of helicopter on the roof of a building designed as a landing pad
Frequency associated with a time interval (t_1, t_2)	During a time interval (in which an accidental action hazard can be considered to be constant)	Period of a very high precipitation which can cause heavy flood or landslide; repair or upgrading of equipment in the plant running a hazardous technology

A major industrial accident will cause consequences C_i which may be measured using all types of the significance $\boldsymbol{S}_i$ indicated in the expression (2). In case where accident is caused by a sudden release of mechanical or thermal energy, the consequences C_i will include damage to structures and large structural objects which are traditionally assigned to mechanical engineering. This damage will cause direct and indirect monetary losses S_{i1} and S_{i3}, loss of time S_{i4}, and, what is possible, the loss of longevity S_{i5} resulting from damage accumulated during the accident.

If accidents in industry, transportation, exploration, and mining are considered from the positions of the structural engineering, they can be broadly classified into two groups:

1. Accidents which involve structural failures contributing to the escalation of accident scenarios; however, these failures are only partial contributors to accident consequences C_i. These are more complex than structural failures (e.g., explosion at Nypro factory in Flixborough (1974), explosion in Texas city (2005), see Broadribb 2008).
2. Accidents which occur mainly as structural failures; their consequences C_i are almost fully determined by negative structural events (e.g., collisions of vehicles with bridges, explosions of domestic gas in dwelling houses, dam failures during severe floods).

QRA can be used as a general methodology for assessing risk of the aforementioned groups of accidents. Accidents belonging to either group occur as shorter or longer sequences of physical events which are formalised in QRA as random events.

4. Accidents with partial contribution of structural events

Accidents belonging to the first group are usually devastating disasters. A sad and well-known example of such an accident was the Flixborough explosion, UK, 1974 (Figs 4, 5). On June 1, 1974, the Flixborough Works of Nypro (UK) Limited experienced a massive vapour cloud explosion. 28 employees were killed and 36 injured (18 of the fatalities were in the control room building, which collapsed during the explosion). In addition, hundreds of persons off-site were injured, 53 with injuries significant enough to be classified by the authorities as "casualties." Fortunately, there were no off-site fatalities, and the on-site fatalities were limited by the fact that the explosion occurred during the weekend. The explosion and subsequent fires totally destroyed the plant, which was never rebuilt. Over 1800 houses and 167 businesses in the surrounding communities were damaged. Subsequent investigation revealed that the most likely the cause of the explosion was the failure of a temporary piping modification that had been made approximately 8 weeks ago (Høiset *et al.* 2000; Skelton 2001; Venart 2004, 2007). When the piping failed, an estimated 30 tons of cyclohexane vapour were released. The resulting vapour cloud found an ignition source, producing a deflagration (there is some speculation that the explosion could have been a detonation) releasing the energy equivalent of about 16 tons of TNT (trinitrotoluol).

An accident belonging to the first group will occur as a sequence of adverse events. In addition, such accident can have numerous scenarios. Thus the *i*th scenario is represented by the sequence of events $E_{i0}, E_{i1}, E_{i2}, \dots E_{in_i}$, where $E_{i0} \equiv E_0$ is the initiating event. The conditional probability of the *i*th consequences is expressed as the product of the conditional probabilities of individual events E_{ij}:

$$P(C_i \mid E_0) = \prod_{j=1}^{n_i} P(E_{ij} | E_0 \cap E_{i1} \cap \dots \cap E_{i,j-1}) \cdot \qquad (3)$$

Fig. 4. The remains of the Nypro chemical plant at Flixborough after the massive vapour cloud explosion, June 1974 (CCPS 2005)

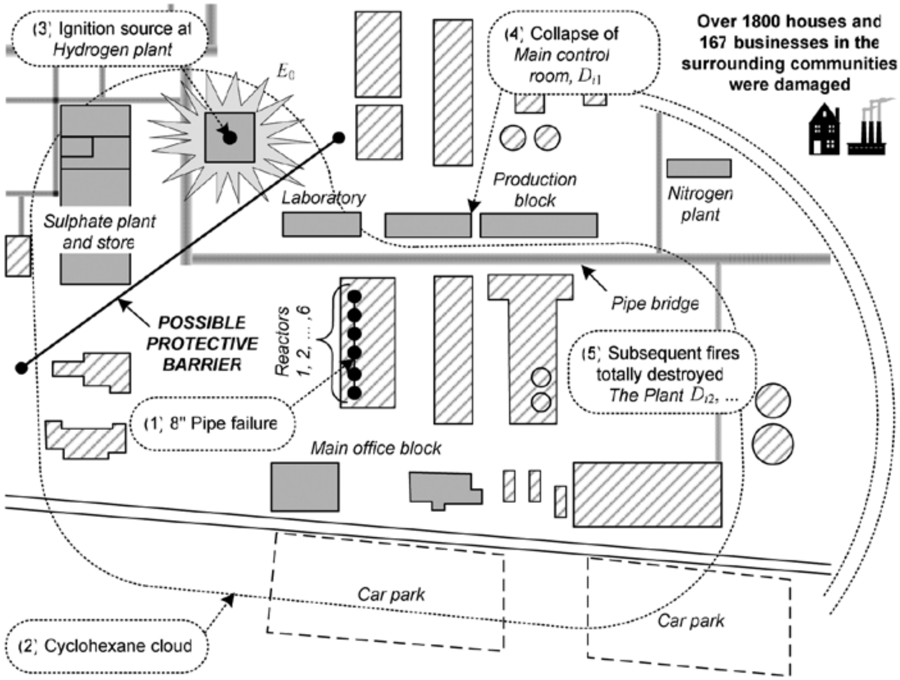

Fig. 5. Simplified accident scenario at Nypro Works, Flixborough, 1974 (Høiset *et al.* 2000) and possible separation of ignition source (hydrogen plant) at Nypro factory using protective barrier

Some of the events E_{ij} can be structural failures which may contribute to further escalation of the accident (domino effect). For example, the accident in Flixborough occurred mainly due to initial explosion of vapour cloud. However, this explosion caused ruptures of piping and tanks and these escalated into further release of flammable gases and secondary explosions. The event tree path shown in Fig. 6 illustrates the "contribution" of the structural events E_{i1} and E_{i5} to accident consequences. Hence, the conditional probability of the *i*th consequences will depend, inter alia, on the probability of structural failures given an accidental action (accidental explosion), namely, the probability $P(E_{i5} \mid E_0 \cap E_{i1} \cap ... \cap E_{i7})$. Thus, the event E_{i5} means damage to a structural object. In what follows, events of this type will be denoted by the symbol D_i. With this symbol, the above probability can be expressed as

$$P(D_i \mid AA) \equiv P(E_{i5} \mid E_0 \cap E_{i1} \cap ... \cap E_{i4}), \tag{4}$$

where *AA* is the random event expressing an occurrence of an accidental action.

Real-world examples of the damage event D_i can be retrieved from the post-mortem investigations of the BP Texas City accident (2005). It was caused by a severe explosion and generated a lot of structural damage inside and outside the BP facility (Khan, Amyotte 2007; Broadribb 2008; Kaszniak, Holmstrom 2008). Two specific damage events D_i are shown in Figs 2 and 3, namely, damage to building with portal steel frames and damage to technological

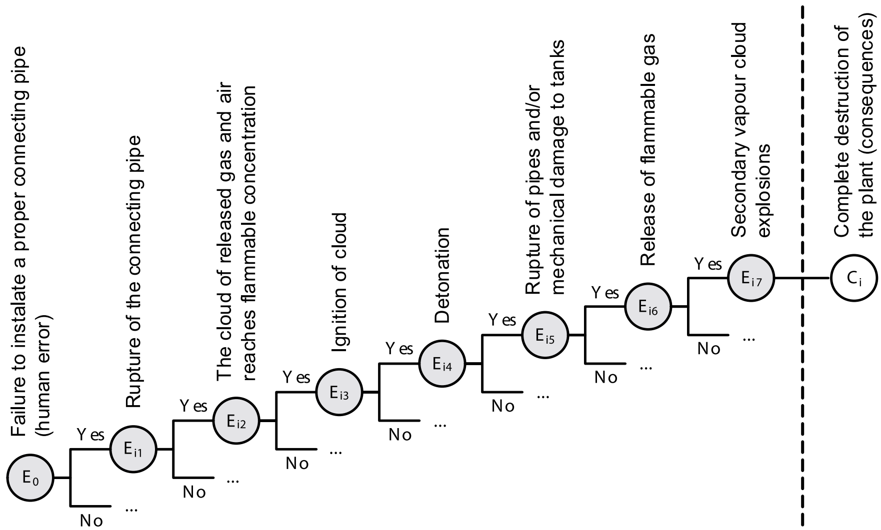

Fig. 6. Event tree path that resulted in the complete destruction of the plant at Nypro factory, Flixborough

piping. They occurred almost coincidentally and were caused by the same explosion (event *AA*). In all likelihood these events did not contribute to further escalation of the accident; however, they definitely contributed to the total consequences of the accident.

5. Accidents occurring mainly as structural events

Another group of accidents, which are worth to mention in the present overview, are accidents with consequences C_i posed mainly by structural failures D_i. Such accidents belong to the second of the two aforementioned groups (Sec. 3). An example of the accident with consequences caused mainly by the damage to structures was the semi-truck collision with bridge (I-70 road, US, 2007) (Fig. 7) (Gallegos, McPhee 2007). The truck was on I-70, when the driver lost control, then overcorrected twice. The truck tore out 22 m of protective barrier before the passenger side of the sleeper cabin hit the bridge support column on the right. The trailer continued past the truck, then both caught fire. The fire scorched the road and overpass. Engineers from Colorado Department of Transportation initially closed all lanes on the bridge and on I-70 road for the clear-out of accident place and evaluation of strength and stability of the bridge.

From the standpoint of QRA, a vehicular impact on the bridge can be treated as an initiating event E_0. In case where the collision does not trigger of a fire or an explosion of the cargo carried by the colliding vehicle, the events following E_0 will be of mainly structural nature. Sequences of these events may result in one of the possible damage events D_i (damage states of the bridge). An example of the events D_i is presented in Table 3.

Fig. 7. The Road 26.5 bridge in Grand Junction (Colorado, US) lost a support column and was closed after it was hit by a semi-truck on August 15, 2007

Table 3. Damage events D_i and consequences C_i likely to occur due to vehicle collision with the bridge ($i = 1, 2, \ldots, 5$)

Possible damage events			Consequences
Minor damage to protective barrier	C_1	=	Short-term traffic restriction due to clear-out of accident place; longer, though relatively short traffic restriction under the bridge due to repair of the protective barrier
Failure of protective barrier and minor damage to support column	C_2	=	The same as C_1; the direct monetary losses will be higher due to the of the supporting column
Failure of protective barrier and moderate damage to support column	C_3	=	Minimal negative influence of the traffic infrastructure; higher monetary losses then C_2 due to significant damage to support column
Failure of protective barrier and reparable damage to support column (the column retains most of its carrying capacity); minor damage to the girder	C_4	=	High monetary losses due to repair of protective barrier, support column and girders; loss of longevity
Total collapse of the bridge structure	C_5	=	Long-term traffic restriction due to reconstruction of bridge; high direct monetary losses and lost time due to bridge repair; high indirect monetary losses due to long-lasting traffic restriction

The accident involved consequences C_i related to direct monetary losses S_{i1} (substantial damage to protective barrier and failure of support column), fatalities S_{i2} (two truckers died), lost time S_{i4} (all lanes were closed for clear-out of accident place, one lane reopened after 7 hours), and possible longevity loss S_{i5} due to moderate damage to girders and span. Possible damage events and consequences of similar accidents are represented in Table 3. They range is from the minor damage D_1 to the loss of the entire bridge structure, D_5. It is obvious that the events D_i themselves are possible consequences of the collision accident. However, the events D_i will pose further consequences which will impair the road infrastructure to a greater or lesser degree. Therefore, the events D_i can be associated with consequences C_i reflecting the degree of disturbance to the traffic.

In case of the accidents belonging to the second group the probability of consequences C_i will be calculated as a probability of the corresponding damage event D_i

$$P(C_i \mid E_0) = P(D_i \mid AA) \cdot \qquad (5)$$

The damage event D_i can be a sequence of random events of structural nature, for instance, a result of progressive collapse inside of a structural system (e.g., Ellingwood 2005; Ellingwood and Dusenberry 2005). In such a case, D_i can be expressed as a union of failure events $\bigcup_{j=0}^{n_i} E_{ij}$. A simple example of the event sequence $E_{i1}, E_{i2}, \ldots, E_{in_i}$, can be presented by considering the potential failure modes of the bridge shown in Figs 8 and 9:

E_{i1} = disintegration of support column (Fig. 9a).

E_{i2} = the opposite support column fails to resist excentrical compression applied by the transverse beam (Fig. 9b).

E_{i3} = the external girder looses support provided by the transverse beam and fails due to an increased span (Fig. 9c).

E_{i4} = the middle girder looses support provided by the transverse beam and fails due to an increased span (Fig. 9d).

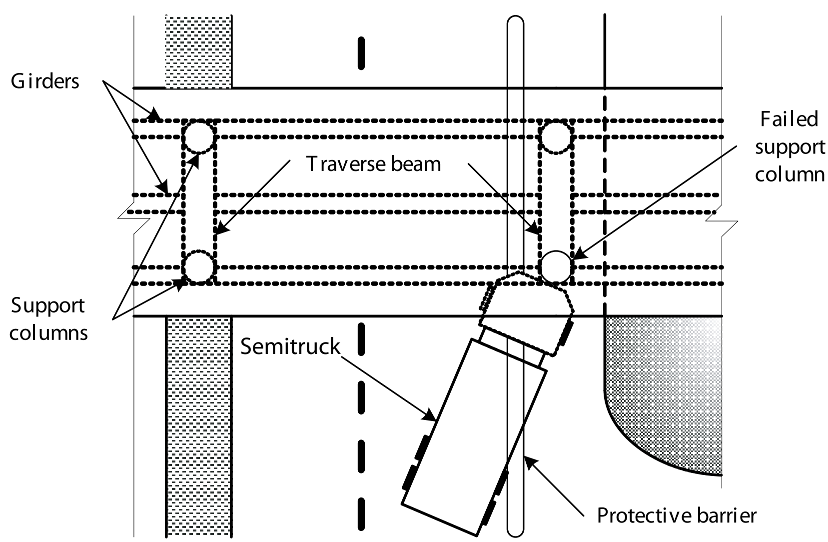

Fig. 8. Simplified schematic visualisation of the road 26.5 bridge damaged in Colorado accident

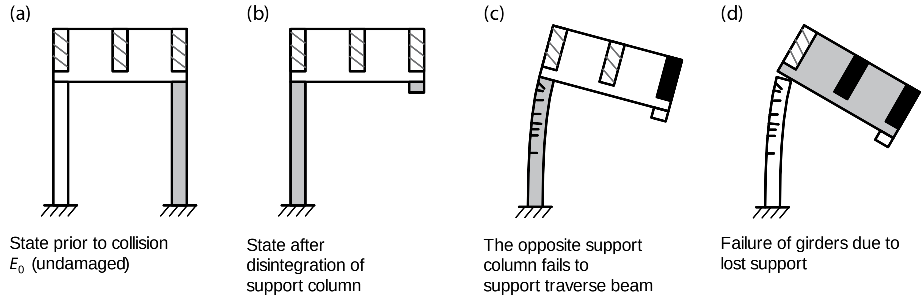

Fig. 9. Simple visualisation of the event sequence of the road 26.5 bridge failure in Colorado accident

In this example, $n_i = 4$ and an occurrence of the event sequence E_{i1}, E_{i2}, E_{i3}, E_{i4} practically means the complete loss of the bridge with the maximum consequences C_5. Clearly, members of the bridge can sustain the damage and this can be limited to one of the events preceding E_{i4}. For instance, the damage can be limited to the event E_{i2}, as shown in Figs 7 and 9b.

The phenomena represented by the events C_i, D_i, and E_{ij} are far from daily ones. They may occur only once per life of hazardous facility or do not occur at all. However, the potentiality of such events is always present in many businesses. A quantification of the measures expressing the likelihood of C_i, D_i, and E_{ij} is the problem which is in focus of QRA. Therefore, it is worth to utilise mathematical tools developed in QRA for the analysis of structures exposed to the potentiality of accidental actions. First and foremost methods of QRA can be beneficially applied to the estimation of the probabilities $P(D_i \mid AA)$, and $P(E_{ij} \mid \cdot)$. In cases where these are probabilities of rare and adverse structural failures, their estimation in line with QRA may substantially differ from the estimation applied in the traditional structural reliability analysis, to say nothing about the usual deterministic structural design (e.g., Aven and Rettedal 1998; Baker *et al.* 2008).

6. Conclusions

The process of sustainable development is vulnerable to various factors which can be of economic, social or environmental nature. Major industrial accidents are among them. A simple, quantitative relation between the continuity of sustainable development and a specific major accident, which may happen in a specific hazardous industry, is difficult to establish. However, the existence of this relation is difficult to deny. Such accidents as Chernobyl nuclear power plant failure or chemical disaster in Bhopal are obvious proofs for that.

Major accidents often involve hazardous releases of large amount of energy and severe damage to the structural components of industrial infrastructure. In many cases, structural components can be "key players" in sustaining hazardous phenomena and mitigating consequences of major accidents. A consistent approach to managing the risk posed by major accidents should be based on an extensive application of the quantitative risk assessment. As failures of structural components belonging to the industrial infrastructure can be essential contributors to accident escalation, these failures should be regarded in the process of the risk assessment.

The role of a particular structural component or system belonging to an industrial facility can be consistently assessed only by treating its potential failure(s) within the methodological framework of risk assessment. This requires a systematic application of risk-oriented approach to structural analysis and design. In many cases, a properly designed protective structure, say, double hull oil tanker, will allow to avoid those accident scenarios which can pose catastrophic consequences and so have negative impact on the progress of industry. Indirectly these consequences may have restricting influence on sustainability of the whole economy. It is natural to anticipate that this negative influence will be minimised if the risk-oriented approach to design of structures to be built in hazardous facilities becomes a common practice in the field of structural engineering.

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RIZIKA GRINDŽIAMOS KONSTRUKCIJŲ INŽINERIJOS ĮTAKA MAŽINANT SUNKIŲ PRAMONINIŲ AVARIJŲ POVEIKĮ DARNIAM VYSTYMUISI

E. R. Vaidogas, V. Juocevičius

Santrauka

Darnus vystymasis gali būti stabdomas sunkių pramoninių avarijų, kurių kartkartėmis nutinka pavojingose pramonės įmonėse. Beveik kiekviena sunki avarija gali turėti neigiamą įtaką vienam iš trijų darnaus vystymosi komponentų: socialiniam, gamtiniam ir ekonominiam. Būdingas beveik kiekvienos sunkios avarijos bruožas yra rimti konstrukcijų, stovinčių tiek avariją patyrusioj gamykloj, tiek ir už jos, pažeidimai. Norint išvengti tokių avarijų ar bent mažinti jų pasekmes, konstrukcines sistemas reikia projektuoti taikant rizika grindžiamą požiūrį. Rengiant detalų projektą reikia naudoti matematinį rizikos matą, kuriuo galima išreikšti konstrukcinių sprendimų efektyvumą, užkertant avariją ar mažinant jos pasekmes. Projektavimas turėtų aprėpti galimų avarijos scenarijų analizę bei teigiamą ar neigiamą konstrukcijos įtaką potencialiam avarijos eskalavimui ar deeskalavimui. Tai galima atlikti pasitelkiant projektavimą, kuris yra orientuotas į riziką. Metodologinis tokio projektavimo pagrindas yra kiekybinis rizikos vertinimas. Sistemingas jo taikymas yra vienas iš rizikos valdymo būdų, leidžiančių sumažinti sunkių avarijų skaičių ir neigiamą jų įtaką darniajam vystymuisi.

Reikšminiai žodžiai: darnusis vystymasis, pramoninė avarija, rizika, mechaninė pažaida, pasekmės, gaisras, sprogimas, susidūrimas.

Egidijus Rytas VAIDOGAS is PhD, Professor of Dept of Occupational Safety and Fire Protection at Vilnius Gediminas Technical University, Lithuania. His major research interests: structural reliability, design of structures for accidental loads, application of risk analysis to safety assurance of structures.

Virmantas JUOCEVIČIUS is a PhD student at Dept of Occupational Safety and Fire Protection at Vilnius Gediminas Technical University, Lithuania. BSC (2005), MSc (2007) from VGTU. Research interests include fire safety engineering, design of structures for accidental loads, statistical modelling of structures.