The staple issues for existing and new buildings in Mid-America seismic areas

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ABSTRACT

The purpose of this paper is to address the six related issues identified by CUSEC in making the Mid-America region safer from earthquakes and other natural hazards within the context of the built environment. These six staple issues are the Social, Technical, Administrative, Political, Legal, and Economic issues. These issues are challenges to the creation of a strategy of creating a safer community in Mid-America. The focus of this paper will be on the buildings and the infrastructure to support the continued use of the buildings after a disaster. The four specific points to be addressed in the paper, within the staple context, are the potential impacts on the community, the need and the use of earth sciences, disaster statistics, and using a system planning approach in the development of the strategy to cater for the building issues.

1. INTRODUCTION

CUSEC (1999) is proposing the development of a strategy to improve the earthquake preparedness of the Mid-America region. This strategy considers the STAPLE issues in the development of the operational plan for the coming decade. The purpose of this paper is to investigate aspects of the development of the CUSEC strategy related to the building and building infrastructure. The paper will investigate the structural, non-structural, and human aspects of the building environment within the relevant STAPLE categories. The areas of direct interest are the systems approach to the communities’ response to the next earthquake, the earth sciences, and the earthquake impact on the built environment. The first aim is to consider a suitable systems model for the built environment. The second aim is to consider the elements of the systems plan that can reduce the earthquake impact, to consider the economic costs of the various elements in terms of the buildings and the occupants of the buildings. This is a brief review of the potential use of the systems analysis approach to the problem of earthquakes in the eastern and central United States (CEUS).

2. LITERATURE REVIEW

The CUSEC (1993) Conference on Earthquake Hazard Reduction in the CEUS context provides a clear set of directions as to the impact on the community of natural hazards such as earthquakes. The series of monographs proceeds to look directly at the six aspects of the reduction of hazard. These papers gave a clear and lucid picture of the issues and problems in the early 1990s.

There is no comfort in the fact that there has not been a major earthquake in the CEUS since that time. Any reasonable consideration of the earthquake statistics and paleoseismological studies since the 1811-12 earthquake swarm could reasonably conclude that another such swarm is not

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expected in the next decade. However, an earthquake of magnitude M5.5 to M7 is probably due in the CEUS. It will probably occur along the line connecting the series of faults that stretch from New Madrid to Maine or along the spur to Charleston. This points to a high risk in an area that is an economic base for the United States and the global economies. Any disruption to the regional economy and the flow on to other economies should not be underestimated or discounted. The research in the CUSEC (1993) document has been followed by research on insurance issues (Kleindorfer and Kunreuther, 1998) and the development of a strategic plan for reducing earthquake losses (CUSEC, 1999). The basis of and the need for such a strategic plan are considered self-evident.

The CUSEC (1999) strategy lists a number of elements that have a benefit cost ratio given as greater than one. It is difficult to envisage any government spending public funds at a B/C ratio less than two. This issue is relatively easy to measure for a particular area by establishing the B/C ratio used to clear up road black spots.

3. SYSTEMS ANALYSIS

The vulnerable systems model of disaster provides a picture of a one to one relationship between a vulnerable population and the socioeconomic system on one plane and the trigger event on the other plane. This vulnerable systems model of disaster could be amended to include a time and spatial separation plane as shown on Figure 1.

Fortune and Peters (1995) concentrate on the human population. The translation from the system vulnerability shown in Figure 1 to the vulnerable systems model of disasters is shown in the translation from the main elements to the Insert shown on Figure 1. This Insert depicts the vulnerable systems model at the initiation of the currently considered event. These authors used the example of the Bhopal disaster in which 3000 people died as a significant hazard. In earthquake terms, an event in which 5000 people die occurs on average every 900 days.

The addition provided to the system vulnerability model shown in Figure 1, which is based on the model of Fortune and Peters (1995), is the addition of an explicit time and spatial separation scale. This element is critical in examining events that follow the Gutenberg-Richter law and that can have a variable distance between the initiating trigger and the vulnerable population.

The change from a particular event, such as Bhopal that is not likely to be exactly repeated, to an ongoing series such as earthquakes involves the use of the time scale and a distance scale. Three

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3 One can point to papers by Nuttli, Beavers, and Ketter to support this view, to the extent that this information is considered in the public domain.
4 In this case, I will define this as east of the 100th meridian and within the continental US.
5 An EXCEL regression analysis of the USGS data for longitude and latitude, for earthquakes since 1973, provides 0.95 regression coefficient on a linear plot between New Madrid and Maine. This supports the results shown on the USGS Hazard Maps and the basis for this is explained in Marshak’s recent papers.
6 It is of course to be hoped that this commission will be created and have some impact before the next major event. Otherwise, it can be expected to be enacted after the inevitable event in the usual short window of major change associated with earthquakes.
7 The first author’s experience with black spots in Maitland is that the New South Wales government criteria for life safety and injury were a B/C of two. A black spot is an engineered area where deaths occur and where a design change will result in fewer deaths. It is typically applied to dangerous intersections.
8 Fortune, J., and Peters, G., (1995), Learning from failure, The Systems Approach, Wiley: Chichester, pg. 239, Figure 10.3.
9 This type of forensic engineering is about learning from failure. There is little to be learned from repeated success with the same product. The learning process can be both pre and post event. We can learn both from the world directly about us and from the world that is isolated from our particular place.
events are depicted in Figure 1. The first event has already occurred. The second event is now or to come. The third event is yet to come.\textsuperscript{10}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Human system vulnerability to earthquakes (after Fortune and Peters, 1995).}
\end{figure}

If we define the system state as the political and economic realities at a particular instant, then the extensive earthquake literature documents the change in this system in the last 150 years since earthquake engineering became a recognized field. The rather interesting feature is the differing worldwide rates of this system change, when compared to most other major-engineered human systems, such as telecommunications. The system-state change function is shown explicitly in Figure 1.

We shall assume for the purpose of this paper that the system-state change variable is measured over a homogeneous region and that we are only concerned in this paper with this region. The explicit enumeration of the system-state change function provides a measure of the current rate of change of the preparedness for the system components and the population. The system-state change function is deemed to have singularity points, which occur at felt events. The step may only be a raised awareness of the earthquake vulnerability, such as after the Milledgeville event of January 18, 2000.\textsuperscript{11} Alternatively, it can be a change in the basic paradigm of the regulatory systems, such as after the Long Beach event of 1933.\textsuperscript{12} The window of opportunity for a paradigm change is immediately after an event that causes significant loss of life or economic damage. This provides a suggested form to the system-state change rate with time. This suggested rate of change is presented in Figure 2. The factors that have been identified as defining the system state are at differing levels of maturity in the CEUS.

\textsuperscript{10} The issue of doublets or a swarm of events is a real concern. In this definition, no size limit is placed on the earthquakes within a swarm.
\textsuperscript{11} USGS QED event report, January 2000.
We review a few factors in the system state, which are relevant to Mid-America, in the response and regulatory function. These factors do not cover a full system state. The emergency preparedness in some communities, in the EUS, is at a level with the best in the world. The ability of Fairfax County, Virginia to respond within hours to an international event is an example of this preparedness. The occurrence of tornadoes, snow, and hurricanes CEUS has provided a base to support the need for emergency preparedness that is well co-ordinated and with a population that is aware of these issues. Regulation has reached a stage where the theoretical requirements to control for earthquake death and damage are mature in advanced interplate regions.

![Figure 2 Rate of Change of the System State](image)

**Figure 2 Rate of Change of the System State**

*Human factors and culture* provide the awareness level to disaster. The success of Project Impact demonstrates an increased cultural awareness to natural disasters that FEMA has vigorously promoted in the United States. The low insurance rate at 10 percent of insured houses does suggest an underestimation of the probability of earthquakes by the average citizen; Kleindorfer and Kunreuther’s comments on this probability issue are applicable. *Infrastructure/maintenance and complexity* suffers from the greatest inertia in the CEUS because of the cost, complexity of the problem and the populations’ perception of the problem. The CEUS has not suffered a major earthquake in over a century. The current position of the system state variable is thus influenced by the lapse in time between the Charleston event and the next major event, which will have a period of more than a century.

The broad categories that are presented in Figure 1 are regulation, human factors and culture, emergency preparedness, complexity and infrastructure. So within these broad categories and mindful of the economic constraints, the aim of any strategy is the optimal application of resources to the given problem. The difficulty of course is that the strategy has to account for an event at an unknown location, of unknown size and unknown time. Therefore, the pre-event

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13 Kleindorfer and Kunreuther postulate that when the public perceives the probability of the occurrence of some events to be lower than it actually is, they are led to an unrealistic feeling of security and safety where the event in question is concerned. Because public perception is that the event is unlikely to affect them directly, they are not inclined to take suitable precautions to avoid dangerous situations. In fact, this false sense of security often leads them to walk in harm’s way when a more realistic assessment of the dangers involved would persuade them to avoid such a situation.
optimal solution looking forward in time is not necessarily the most optimal solution if the location, size, and duration of the event were known. Therefore, it is not like preparing for a Bhopal disaster near a known plant. It is like preparing for a Bhopal disaster anywhere and any magnitude. In those terms, the optimal strategy must consider the allocation of resources to planning, prevention, regulation, and mitigation. The optimal strategy may well be the planning strategy and the preparedness, but no mitigation. The systems analysis is designed to determine the route to a planning strategy that is acceptable to the current community, who are realistically informed of the level of the risks.

3. SYSTEMS APPROACH

3.1 Introduction

A simple consideration of the populations’ political desire to expend funds on earthquake preparedness, given the factors outlined in the paper, suggests a review of the alternatives and a consideration of the benefit and the likely loss. It is not intended with this paper to cover the broad range of strategies present in the CUSEC plan. We are concerned with elements of the systems approach, and considering the place of three examples in the overall strategy. These alternatives considered are:

- Geophysical investigations
- Disaster statistics
- Systems analysis – development of objective functions

3.2 Geophysical Investigations

One method for providing a forecast of the range of impacts and to provide a feel for the time based probability rather than the frequency domain of the Cornell method is to use the Monte Carlo method used by Ebel and Kafka (1999) for the Boston region. The work of Marshak and Paulsen (1997) provides a base methodology to then refine the search and extend the recent geosciences work by the MAE Center on New Madrid Zone to other areas that have not been as well researched.

The final economic issue relates to the potential benefit to cost of any proposal. The development of a refined model to improve the probability estimates for the time domain earthquake estimates for the next century is a clear and high benefit to cost return for the community in terms of earthquake safety. A refined model with an improved probability density function will provide a clearer target for the expenditure of limited funds to minimize the losses within existing developed areas and has the advantage of being able to estimate the demand surge from alternative event scenarios.

The essential aspect is identifying the potential meizo-seismal areas. In this case defined, as about 25 – 30 kilometres wide where the fatalities count will likely be appreciable. The simple economic models demonstrate the clear cost benefit in anticipating these areas and working to reduce the human costs. In terms of the existing building stock in the areas at a distance from potential meizo-seismal areas the level of expenditure that fits with a reasonable benefit to cost ratio must be governed by the potential loss to the national assets. The interesting feature is of course the secular and specific interests of the different sub-groups within the US do not always provide the opportunity to mitigate the losses either before or after a disaster.

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A passage of 38,325 days from the last major CEUS event has meant that there has been little opportunity to learn from earthquake failures in the CEUS. The success in the face of zero loading is not a true measure of the engineering environment. The development of further earth sciences advances is a significant step in the arsenal against earthquakes.

3.3 Disaster Statistics

The lessons from the Kobe, Napier, and Tangshan earthquakes need to be applied sensibly to the CEUS. Nichols et al., (2000a, b) have recently hypothesized a synthetic fatality function for earthquakes. This function has been used to compare data from the Napier 1931, NZ, Long Beach 1933, and the Tangshan earthquake. The hypothesis is poorly tested at this stage, but the data indicates that further data collection and analysis is warranted. The function was used to estimate the death toll in Wellington NZ, caused by a movement on an adjacent fault.

The estimated death rate of 1 to 3 percent is consistent with estimates for Memphis. This rate corresponds to about a 15 percent damage level. This should be compared to a 33 percent death rate when the building collapse equals 100 percent.

This function was used to consider the likely fatality rate for Wellington, NZ for two alternative earthquakes on the adjacent fault. The results provided for the estimated costs for a housing unit damaged in each specific event at Wellington are summarized in Table 1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit Rate</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home value</td>
<td>$US 75,000</td>
<td>150,000</td>
<td></td>
</tr>
<tr>
<td>Fatality Rate</td>
<td>Percent</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Injury Rate</td>
<td>Percent</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Home Damage</td>
<td>Percent</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Fatality Loss</td>
<td>$800,000</td>
<td>$8,000</td>
<td>$24,000</td>
</tr>
<tr>
<td>Injury Loss</td>
<td>$10,000</td>
<td>$300</td>
<td>$900</td>
</tr>
<tr>
<td>Home Loss</td>
<td>16 percent</td>
<td>$12,000</td>
<td>$24,000</td>
</tr>
</tbody>
</table>

These costs can be adjusted from US 1980 data using standard economic methods (Rollins and McFarland, 1986). The house values are notional only. The rates are based on three people per dwelling and a 16 percent house damage rate. The fatality results are consistent with the Napier, NZ, and Long Beach, USA fatality counts.

The equivalent Tangshan event in terms of cost per house at 1 in 3 fatalities is $0.25M and 100 percent destroyed is $0.15M. These figures illustrate the clear point for intraplate earthquakes, when compared to interplate earthquakes that the secondary toll in fatalities and injuries even for a low fatality count can out weigh the building loss in economic terms.

15 The fatality function is a postulate that is far from proven, but it does provide a method to account rapidly for some of the fatality factors in differing areas. Considerable further research is required on the function which has the form: $y = \sum_{i=1}^{n} \lambda_i \Xi(x)$, where $\lambda_i$ represents the series of factors that reduce the fatality count because of circumstances at each location, i is the index counter and n is the total number of factors. The factors will be limited to four for this paper. $\gamma = \Xi(x)$ is a fitted function through the peak earthquake deaths for a given magnitude in the 20th century, where the form is based on y being the fatality count and M is the magnitude of the event where $\log(\gamma) = 3.93M - 0.57M^2 - 32.4$ with R² of 0.95.
The costs for a county with a housing count of 300,000 packed into a small meizoseismal area for these three events are presented in Table 2.

Table 2 Estimated Earthquake Costs

<table>
<thead>
<tr>
<th>Event</th>
<th>Fatality Cost $Billion</th>
<th>Injury Cost $Billion</th>
<th>Housing Cost $Billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Scenario 1</td>
<td>2.4</td>
<td>0.1</td>
<td>3.6</td>
</tr>
<tr>
<td>2. Scenario 2</td>
<td>7.2</td>
<td>0.3</td>
<td>7.2</td>
</tr>
<tr>
<td>3. Tangshan Event</td>
<td>75.0</td>
<td>3.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>

This analysis ignores all other damage, consequential losses, and damage in other counties. The work by Cochrane and Schmehl, and Kunreuther (CUSEC, 1993, M. 5, Chap. 6 and 7) provide a clear picture of the impact of this type of loss on the local, regional, and national economy. The distribution of the economic costs of the event is beyond the scope of this paper. There is little doubt given the current level of insurance in Mid-America that a Federal Disaster relief plan would be a prime consideration for the local and regional recovery.

3.4 A systems analysis – development of Objective Functions

Development of objective functions depends on the Weltanschauung of the group that is developing a strategy. Three objective functions could be used in the development of the mitigation functions for the meizoseismal areas. The mitigation strategies for the potential meizo-seismal areas has three objectives:

1. The life safety objective of minimizing the loss of life. The indicator objective must be consistent with the UKHSE standard of 0.01 percent. This is equivalent to 75 deaths in the Tangshan event, whereas the reality is closer to 242,000.
2. The economic objective of minimizing the overall loss to the national asset. These two objectives are interrelated through the fatality costs.
3. The social objective of maintaining the function of the socio-economic system.

The life safety objective should not necessarily be confused with a return period or probability of a particular loading on the structure because of the likelihood of what is euphemistically termed non-structural damage. The time has passed when the structural engineer can remain divorced from the safety of things that are attached to the structure if the structure can accelerate these elements to levels where they pose a crush injury danger. This paradigm shift is clearly indicated in the FEMA 273 document. The satisfaction of this objective will require a far greater understanding of the intraplate tectonics and may require appropriate planning measures in much the same fashion as is evident in flood plain management. It is acknowledged that this represents a difficult political issue and one that will not be resolved in the next decade.

The economic objective is based on the personal Weltanschauung. The prevention of secondary crush injuries will provide a reduction of the losses. One of the critical areas in the economic objective is the issue of transportation. The social and economic disruption of even minor bridge

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16 Weltanschauung. Your personal viewpoint of things.
17 These mitigation functions to some extent are typical of the intraplate scenario and differ from the interplate scenario at least in California and New Zealand, except in areas of existing un-reinforced masonry. This point was reinforced with the recent tragic Kobe earthquake losses. The collapse of the masonry roofs killed a disproportionate number of residents.
outages should not be underestimated. The loss of the Keithsville Bridge in April 1941 and the
more recent flooding outages should be the subject of an economic study. This study should
determine the steps taken to minimize losses and ensure that the lessons learnt in the past are not
lost.

The social objective can be clearly seen in the effect of large-scale death tolls on a small
population base, the Armenian earthquake consequences is a clear pointer to this problem. The
social objective must be to maintain the basic services and town functions, within the broad
objectives of the life safety and economics of the region.

3.5 Comments

This is far from an exhaustive systems analysis of the earthquake problem in the CEUS. The
three areas touched are interrelated to the extent that the development of the objective functions is
a primary step in determining an optimal allocation of resources and the development of a
strategy. The objective functions require an identification of the main issues and gaining some
understanding of the relevance of each issue. Two specific issues provide a pointer to the
objective functions and in turn are potential research areas with a high benefit cost ratio in terms
of earthquake mitigation strategies.

We of course need to consider the use of alternatives that are simply uneconomic. The
retrofitting of every building east of Kansas is obviously a strategy that has a low benefit cost
ratio.

4. STAPLE ISSUES

The six staple issues are the social, technical, administrative, political, legal, and economic issues
that are challenges to the creation of a strategy to cover a decade to reach a goal of creating a
safer community in Mid-America. There are two distinct areas for buildings. The first is the
existing building stock and the second is the development of new building stock. The extent to
which Project Impact will penetrate the community and affect the public and private decision
making processes is one to the interesting side features. Any plan to be acceptable must consider
the place of Project Impact and to look to developing links with this group.

A specific example from this is the development of tornado resistant housing. The secondary
feature is concept of survivability being introduced into the structural lexicon, which sees the
creation of strong rooms for tornado safety in a similar manner to the development of the Morris
shelter in England during WW2. FEMA, the NSF with the three earthquake research groups and
organizations such as CUSEC are raising the awareness of the population as to the impact of
disasters. Any education program developed by these groups will influence the population’s
concept of hazard and risk.

The technical challenges differ for the existing housing stock to the new housing stock. The
recent tragic events in Kobe and Turkey demonstrate the poor seismic resistance of some existing
structures. This potential problem is evident in the Mid-America region with the structural types
that are known to perform poorly being commonplace. The number of deaths in recent
California and New Zealand events demonstrates in part that increased expenditure on seismic
resistance of building reduces the death toll. The technical challenge is the development of
economic methods to strengthen existing structures. This issue immediately flows onto
administrative, political, legal, and economic issues. These issues have been briefly explored in
terms of a systems analysis in the preceding section of the paper.

The Iroquoian concept of a social democracy that extended into the development of the New
England town concept for a political system has the draw back of slowing the development of
administrative and political solutions for the implementation of stricter engineering and planning standards. This problem is resolved in the Australian context with a single building code, which is adopted on a statewide and national basis. This method is developing at the professional level in the US, but its adoption at the local level will be hindered without a consistent Mid-America approach. This is a clear area for CUSEC to assist in this implementation. This is a public safety issue that transcends the social democracy inherent in distinct town units.

Preparedness for an earthquake does not only extend to the engineering, but must extent to the entire social system that the earthquake will affect. The known effects of great New Madrid earthquakes (Richter, 1958) on the CEUS are historically documented. In looking to the development of the systems analysis, one must place a realistic estimate of the likely return period for such events. The realistic analysis would suggest that a lower level event is probable with the larger events possible but likely to be greater than a century in returning.

Within the context outlined in this paper, the STAPLE issues can be considered separately and as a group. Socially the CEUS is ill prepared for a major earthquake in this case defined to be in excess of M5.5 close to an urban area. This problem is being addressed by FEMA with the development of Project Impact communities. The broader social issue requires eduction of the population as to the risk. The old adage of those who do not know history being doomed to repeat the mistakes of the past should not occur in the CEUS. This issue is highlighted by Kleindorfer and Kunreuther’s comments. Technically, the NZ, Japanese, and Californian engineers have developed the seismic art to a stage where the death toll can approach the UKHSE standard. However, the large areas of older housing that has sat undisturbed for centuries can bring death at a high rate. The recent Kobe earthquake deaths along the fault are a classic example of this problem. One would be naïve in the extreme not to consider that Memphis and St Louis face a similar risk.

Administrative, legal, and political problems are compounded in the central and eastern United States because of the form of the governments and their basis in the Iroquoian system of town units. The common law statement that Acts of god are a common enemy is the center stone of the development of a system that can transcend this matter. The issue, whilst not trivial, is certainly one that organizations like CUSEC are focussing attention on and one that will ultimately be resolved because of the economic benefits to solving it.

The economic reality of the modern world is that different regions are in competition with the outside world. FEMA provides a safety net for the US system, however the Central United States is in competition with the world. The inability to ship grain products means that other suppliers will step in and fill the markets. The ability to supply on demand is critical to a successful market economy. The current coal supply represents this well. The economic problem requires an understanding of the consequences of events that may affect the ability of the region to compete. This type of study is required for the central United States.\textsuperscript{18}

\textbf{5. CONCLUSION}

The goal of systems analysis is not the study of systems, but the understanding of the system and the development of methods to ensure that the system is operating at a reasonably optimal level within the Weltanschauung of the group that is concerned with the system. System change can occur because of outside influences or because of some acceptance that a problem is present and that something needs to be done about the problem. The difficulty east of Kansas is that the public’s perception of the risk of earthquake events is lower than the reality. The cost of resolving this problem by awaiting an event may bear tragic and high economic consequences for

\textsuperscript{18} Cochrane noted in a recent conversation that this type of historic economic study has not been completed for even simple outages on bridges over the Mississippi River.
the region. This paper has briefly toured the use of a systems analysis approach to earthquake engineering. This is neither a thorough nor a rigorous approach, but it does highlight the potential of this approach. The issues identified in this analysis simply point to areas of potential research. The need for a co-ordinated approach to the seismic issue within the context of the STAPLE issues has been addressed in this paper.

6. REFERENCES


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