Research on Seismic Reliability Criteria of Urban Lifeline Network Systems

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ABSTRACT

Urban lifeline network systems are the material base of urban health operations. The components damage and function loss of lifeline system are caused by strong ground motion. Urban lifeline system can continue to run that after the event, the seismic reliability of urban lifeline network must be reasonable determined. Based on the network system characteristics, the three network elements namely nodes, routes and flow of various lifeline systems are given. The especially important components to reduce earthquake disaster in lifeline network system are puts forward clearly. Connectivity, maximum flow, service and economic loss as a quantitative measure of lifeline engineering system network performance. Connectivity, maximum flow, service and economic loss are regarded as the representative quantitative measures of network performance. The performance standards of lifeline system consist of three aspects by quantitative expression as followed: the number affected by interrupted lifeline, the disaster influence range affected by interrupted lifeline and the time required to complete repair after earthquakes. The performance standards of lifeline system are classified by the total number, the disaster influence range affected by interrupted lifeline and the time required to complete repair after earthquakes. And the seismic reliability criteria of urban lifeline network systems are suggested finally.

INTRODUCTION

Lifeline are the sum of systems and networks who are essential for maintaining urban functions, such as transportation system, communication system, power supply system, water supply system, drainage system, gas supply system, oil transmission system and so on. Modern city highly depend on various types of lifeline systems. Seismic reliability of lifeline system is a main content of urban disaster prevention planning. Actual earthquake damage data show that lifeline systems are vulnerable.

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The bigger city scale and the higher modernization degree, the greater the loss caused by earthquakes. The Loss usually include public utilities service interruptions, direct economic and property damage, secondary disasters loss, unemployment, natural environment disaster and so on [1][2]. Therefore, the seismic reliability levels of lifeline network systems need to be determined. The network reliability is effectively increased and the aseismic capability of the whole system is improved.

CLASSIFICATION AND COMPOSITION OF LIFELINE SYSTEM

 Lifeline system is the combination of structural engineering and system engineering in essence. The main characteristic compare with general building structure is that the distributions of components are in a large geographical scope, every component of the system under seismic actions may be different. Systems have network characteristics. A damage location may affect the function of a region and even the whole network system. Based on the network theory, a network consists of three elements, namely nodes, routes and flows [3]. The corresponding meanings of three elements for network model are listed in table 1.

| Classification of Lifeline System | Nodes | Routes | Flows |
|----------------------------------|-------|--------|-------|
| (1) Energy System                | Power Plant, Substation, Gas Station, Gas holder | Power Supply Line, Gas Pipeline | Voltage, Current, Gas flow, Pressure |
| Gas Supply System                | Oilfield, Oil Refinery, Oil Tank, Pumping Station | Oil Pipeline | Oil flow, Pressure |
| Oil Transmission System          | Water Source, Water Plant, Pumping Station | Water pipeline | Water Flow, Pressure, Flow Rate |
| (2) Water                        | Sewage Treatment Plant, Pumping Station | Drainage Pipeline | Displacement |
| Water Supply System              | Communication Center, Base Station, Interchange Station, User | Communication Link | Communication Capacity, User Numbers |
| Drainage System                  | Traffic Lines (Including Large Bridges, Tunnels) | Transportation Amount | |
| (3) Communication System         | Station, Port, Wharf, Airport | |
| (4) Transportation System       | |

Among them, some nodes itself is a small system, such as power plant, water plant and so on. Therefore the diversity of three elements of lifeline system make the seismic reliability analysis work become complex problems, so effective analysis methods must be used to calculate typical parameters reflected the function reduction or failure of network system instead of just individual nodes and routes. And the nodes and routes in different parts should be treated differently at the same time.

COMPONENT VULNERABILITY OF LIFELINE SYSTEM

In general, the ground component vulnerability is primarily from strong ground motions. But the seismic damages of underground structures are mainly the foundation
failure effect such as permanent ground displacement, settlement, fault and liquefaction besides the ground motion. Some components in function and operation or huge investment of lifeline system are particularly important. These components under seismic action are damageable or difficult to repair, which damage will cause huge economic losses, directly endanger personal safety and health. So, the vulnerability analyses of important components should be given special attention. The especially important components to reduce earthquake disaster in lifeline network system are listed in table 2.

Table II. The especially important components to reduce earthquake disaster in lifeline network system.

| Lifeline System       | Important Components                                                                 |
|-----------------------|--------------------------------------------------------------------------------------|
| Power Supply System   | Power Plant, Nuclear Power Plant, Cooling                                            |
|                       | Tower, Control Room, Alternating-Direct                                              |
|                       | Current Exchange Station, Backup Generator                                          |
| Gas Supply System     | Pressure Station, Control Room, Gasholder,                                          |
|                       | Pipeline, Nodes at Main Trunk                                                        |
|                       | Oilfield Facility, Refinery, Oil Tank, Pumping                                       |
| Oil Transmission System| Station, Main Valve, Pipeline, Monitoring System                                    |
| Communication System  | Communication Launch Tower, Control Station,                                        |
|                       | Base Station, Communication Center                                                   |
|                       | Bridges, Tunnels, Railway and Road Bed                                               |
|                       | Highway, Navigation Tower, Port Facilities,                                         |
|                       | Communication Apparatus, Metro, Urban Rail Transit                                   |
| Transportation System | Reservoir Dam, Water Treatment Plant, Water Intake Well, Water Storage Facilities    |
|                       | Pumping Station, Pipeline, Water Conduit Bridge                                      |
| Water Supply System   | Intake Well, Water Storage Facilities, Pumping                                       |
|                       | Station, Pipeline, Water Conduit Bridge                                              |
| Drainage System       | Sewage Treatment Plant, Pressure Station, Pipeline, Nearshore Facilities             |

The vulnerability state of components can use two-states, many-states or continuous model to express. The two-states use two opposite states to define, such as damage and no damage, on and off, function and no function. The many-states model expand vulnerability states to many levels, such as basic intact, slight damage, moderate damage, severe damage and destroy. The continuous model is vulnerability function that is component continuum possible states of different destruction expression under seismic actions. Component is the basic unit of lifeline system. The concept of component and system is relative. An object could be regarded as system in some researches, but could be regarded as component in the larger scale. Be regarded as system or component depends on the purpose and precision of research.

**QUANTITATIVE MEASURE OF NETWORK PERFORMANCE**

The representative quantitative measures of network performance are connectivity, maximum flow, service and economic loss. Network connectivity can calculate easily by binary variables. The connectivity of any specific nodes or a set of nodes selected under seismic actions could be calculated, but the connected degree could not be expressed quantitatively further. Maximum flow from any source to any route could calculate easily in a certain load capacity network. Maximum flow is a
better standard to reflect the performance of network system, also could be used to illustrate the boundary value of economic loss roughly. Network service is measured by the percentage of the population in service. It is a multidimensional measure of connectivity, service state of each node can be directly obtained by using the total population in service. Network service is a better relative scale to evaluate performance of all kinds of lifeline system. The most attention scale of network performance is the direct and indirect economic loss caused by under-supply or interrupt. And calculation model should be determined.

THE REFERENCE STANDARD OF NETWORK PERFORMANCE

The performance standards of lifeline system consist of three aspects by quantitative expression as followed: the number affected by interrupted lifeline, the disaster influence range affected by interrupted lifeline and the time required to complete repair after earthquakes [4]. The classifications of performance level for lifeline network system after earthquakes are listed in table 3.

| Performance Level | The maximum percentage of influence number due to service interruptions (%) | The longest interrupting time (days) | The complete repair time (days) |
|-------------------|--------------------------------------------------------------------------|------------------------------------|---------------------------------|
| AA                | Keep complete functions                                                  | -                                  | -                               |
| A                 | 0.1                                                                      | 1/4                                | 1                               |
| B                 | 0.5                                                                      | 1                                  | 7                               |
| C                 | 1                                                                        | 3                                  | 14                              |
| D                 | 2                                                                        | 7                                  | 30                              |
| E                 | 10                                                                       | 14                                 | 90                              |
| F                 | 50                                                                       | 14                                 | 180                             |

The acceptable performance standards of various lifeline systems under seismic actions are given in table 4. The state of reliability level A refers to one day service interruption and one week complete repair in less than 5% of intensity area. The state of reliability level B refers to one week service interruption and one month complete repair in less than 20% of intensity area. The state of reliability level C refers to one week service interruption and three months complete repair in less than 50% of intensity area [5].
Table IV. The suggested reliability levels of various lifeline systems.

| Lifeline System       | Components                            | The reliability under seismic actions |
|-----------------------|---------------------------------------|---------------------------------------|
|                       |                                       | Strong ground motion                  |
|                       |                                       | (Seismic intensity: IX-XII)            |
|                       |                                       | Moderate strong ground motion          |
|                       |                                       | (Seismic intensity: VI-VIII)           |
| Power Supply System   | Nuclear Power Plant*                   | Keep complete functions               |
|                       | Power Plant* (Except Nuclear Power Plant) | A                                     |
|                       | Power Transmission*                    | B                                     |
|                       | Power Distribution*                    | B                                     |
|                       | gas transmission*                      | A                                     |
|                       | Gas Storage*                          | A                                     |
|                       | gas distribution                       | B                                     |
|                       | Oil Refinery*                         | A                                     |
|                       | Oil Storage*                          | A                                     |
|                       | Oil transportation*                   | B                                     |
| Gas Supply System     | gas transmission*                     | A                                     |
|                       | Gas Storage*                          | A                                     |
|                       | gas distribution                       | B                                     |
| Oil Transmission System| Oil Refinery*                         | A                                     |
|                       | Oil Storage*                          | A                                     |
|                       | Oil transportation*                   | A                                     |
| Communication System  | Launch Tower                          | A                                     |
|                       | Broadcast and TV                      | A                                     |
|                       | Telephone                             | A                                     |
|                       | Highway and railway Bridges*          | (don’t collapse)                      |
| Transportation System | Road and railway                      | B                                     |
|                       | Airport Control                       | A                                     |
|                       | Facilities, airport runaway*          | A                                     |
|                       | Reservoir Dam*                        | Do not appear damage endangered the life safety |
| Water Supply System   | Firewater                             | A                                     |
|                       | (proper storage)                      | A                                     |
|                       | Disposal facilities                   | B                                     |
|                       | Water Distribution Network            | (Moving vehicles can be used for water supply) |
|                       | catchment water*                      | C                                     |
|                       | disposal facilities*                  | B                                     |
| Drainage System       | Disposal facilities*                  | B                                     |

**CONCLUDING REMARKS**

To sum up, the following five aspects work need to be researched to determine reasonable reliability level of lifeline network system under seismic actions.

(1) The work of seismic geology and seismology. Area earthquake environment of nodes and routes for lifeline system is determined according to the recognition of potential earthquake source.

(2) The work of structure engineering. According to the characters of each member in lifeline system, the corresponding structural dynamics models is identified, and the seismic vulnerability of each component and their combinations are analyzed.
(3) The work of network theory. The aseismic reliability of the whole lifeline network composed of components or subsystems are analyzed by using effective network analysis methods. The weak links of systems are found out, which will contribute to establish emergency planning and disaster relief planning.

(4) The work of economics. The economic loss caused by earthquakes should be analyzed on the basis of above research work since lifeline systems have generally huge investments.

(5) The work of decision-making. An acceptable balance between cost and risk are sought, which are mainly used for vulnerability assessment, existing system transformation, aseismic reliability level of nodes and routes reasonable confirmation, earthquake insurance and so on.

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