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Development of a Database Framework for Modeling Damaged Bridges

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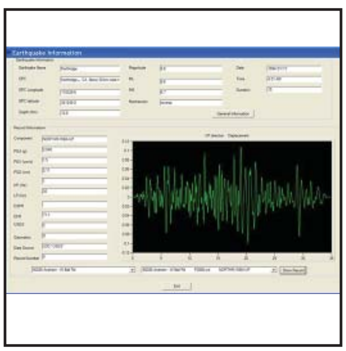
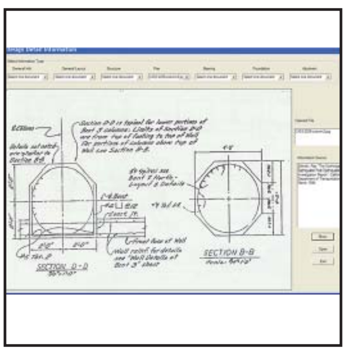
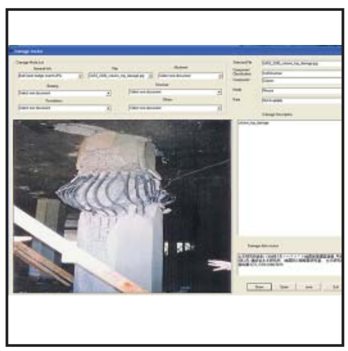
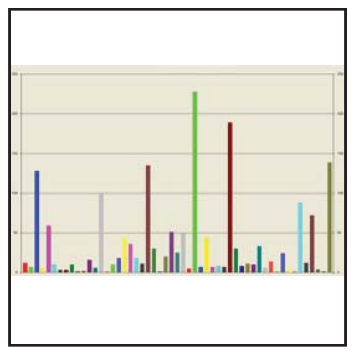

Technical Report MCEER-13-0009

June 16, 2013

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NOTICE

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Preface

MCEER is a national center of excellence dedicated to the discovery and development of new knowledge, tools and technologies that equip communities to become more disaster resilient in the face of earthquakes and other extreme events. MCEER accomplishes this through a system of multidisciplinary, multi-hazard research, in tandem with complimentary education and outreach initiatives.

Headquartered at the University at Buffalo, The State University of New York, MCEER was originally established by the National Science Foundation in 1986, as the first National Center for Earthquake Engineering Research (NCEER). In 1998, it became known as the Multidisciplinary Center for Earthquake Engineering Research (MCEER), from which the current name, MCEER, evolved.

Comprising a consortium of researchers and industry partners from numerous disciplines and institutions throughout the United States, MCEER's mission has expanded from its original focus on earthquake engineering to one which addresses the technical and socio-economic impacts of a variety of hazards, both natural and man-made, on critical infrastructure, facilities, and society.

The Center derives support from several Federal agencies, including the National Science Foundation, Federal Highway Administration, National Institute of Standards and Technology, Department of Homeland Security/Federal Emergency Management Agency, and the State of New York, other state governments, academic institutions, foreign governments and private industry.

The Federal Highway Administration (FHWA) is supporting a study entitled "Principles of Multiple-Hazard Design for Highway Bridges." The project objectives are to establish a number of fundamental design principles and a framework to systematically expand the current AASHTO Load and Resistance Factor Design (LRFD) bridge design specification into a multi-hazard (MH)-LRFD. This is carried out by working closely with Federal Highway Administration experts, the AASHTO Subcommittee on Bridges and Structures (SCOBS) Technical Committee on Loads and Load Combinations (T-5), and with selected individuals who were largely responsible for the development of the current AASHTO LRFD. Several innovative technology developments for the mitigation of and response to extreme events are also part of this project. These include the development of software for a bridge damage database, development of a comprehensive framework for MH-LRFD, extreme hazard load effect calibration, multi-hazard design examples and case studies, traffic optimization software for multiple hazards, freight movement under multi-hazard conditions, development of a curvature sensor for bridge health monitoring, and education materials related to multi-hazard resilient bridges and highway infrastructure.

This study was carried out to establish a framework for the eventual development of a comprehensive database of damaged bridges (DDB) based on bridge damage information available *in the open literature. The proposed database framework described herein integrates current existing bridge information sources with new information to provide a uniform database to use for modeling damaged bridges. The database includes the following information: bridge design information (design documents, construction, drawings, etc.); environmental (geographical and weather) conditions; hazards information and traffic conditions; bridge damage and loss information (damage positions and damage modes, etc.) and economic and environmental impacts. As expected, most of this information is not available, certainly in quantitative terms. Furthermore, in addition to the lack of quantitative descriptions of bridge damage (failures and partial failures), the condition of the bridge at the time of failure is almost non-existent in the documented information/database. This latter information is relevant in damage modeling of bridges. Therefore, the database software described in this report should be regarded as a framework for further refinements, especially in the areas of quantitative information regarding damage and estimated bridge condition at the time of failure.*

Abstract

A bridge can fail for many reasons, including internal causes (design errors, material defects or aging, insufficient capacity, construction errors, etc.) and external causes (extreme events such as earthquake, scour, flood, wind, vessel collision, fire, etc.). Although there are several existing information sources such as the NYSDOT databases, as well as other collected or summarized reports on bridge damage and failures, they do not contain enough information to provide a fundamental basis for further improvement of the Load and Resistance Factor Design (LRFD) specification for bridges. Thus, this study was carried out to establish a framework for the eventual development of a comprehensive database of damaged bridges (DDB) based on bridge damage information available in the open literature. The proposed database framework described herein integrates current existing bridge information sources with new information to provide a uniform database to use for modeling damaged bridges. The database includes the following information: bridge design information (design documents, construction, drawings, etc.); environmental (geographical and weather) conditions; hazards information and traffic conditions; bridge damage and loss information (damage positions and damage modes, etc.) and economic and environmental impacts. As expected, most of this information is not available, certainly in quantitative terms. Furthermore, in addition to the lack of quantitative descriptions of bridge damage (failures and partial failures), data about the condition of the bridge at the time of failure is almost non-existent in the documented information/database. This latter information is relevant in damage modeling of bridges. Therefore, the database software described in this report should be regarded as a framework for further refinements, especially in the areas of quantitative information regarding damage and estimated bridge condition at the time of failure.

Acknowledgment

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INTRODUCTION

Bridge failure may be defined as the loss of a structural component, loss of basic functionality, catastrophic collapse, or any damage condition in between. A bridge can fail due to a variety of single or combination of reasons, including material imperfection or aging, overload, insufficient design capacity, construction error or lack of maintenance. Lessons can be learned through proper study of bridge failures due to these various causes. Similar to reconnaissance studies of damaged or collapsed structures after a natural disaster, design guidelines can be improved through a better understanding of the causes and mechanisms of failure.

In order to carry out useful post-event studies and to learn from past failures, documentation of the damage or failure condition is needed. One way to effectively capture this information and make it useful for design and construction practitioners is to create a database consisting of at least four types of information: hazard information (e.g., U.S. Geological Survey (USGS)), original design and construction information (e.g., the National Bridge Inventory (NBI)), failure information (e.g., the New York State Department of Transportation (NYSDOT) bridge failure database (NYSDOT 2006)) and other information (e.g., economic losses and casualties). Additional information such as historical data about repairs, retrofitting, and lifetime maintenance for each of the failed bridges is also necessary for a full understanding of the modes and causes of failure.

The basic objective of developing a database of damaged bridges is to provide a comprehensive bridge failure database in one repository and use it to improve the reliability of our Nation's bridges. If detailed information about each catastrophic event is made available in an easy-to-understand form, researchers will be better able to digitally reconstruct the event and conduct an in-depth analysis of the capacity of the structure under various circumstances so that future designs can be improved. In addition, computer simulations can help to achieve a better understanding of the loading effect on bridges due to multiple hazards so that a uniform platform for evaluation and comparison can be established based on bridge damage due to a variety of hazards.

In a research project at the University at Buffalo (UB) sponsored by the Federal Highway Administration (FHWA) to explore reliability-based multiple hazard design principles of highway bridges, a subtask is carried out to review existing information and create a database with the following objectives:

1) **Short term**: Establish the distribution and intensities of extreme natural hazard events for the calculation of bridge failure probabilities, and include this information in a database. The database will also facilitate in-depth forensic studies.
2) **Long term:** Expand the database into a comprehensive bridge damage/collapse database (i.e., National Repository) over time to help to continue to improve the AASHTO Load and Resistance Factor Design (LRFD) bridge design limit state equations.

In order to develop a bridge failure database, it is necessary to first define the scope of "failure" and the "entities" of the intended database. These are challenging issues. Currently, there is no commonly accepted definition of bridge failure. This deficiency is evident from a review of available information.

There are several existing information sources on bridges in the U.S., such as the NBI (FHWA 2013) and the NYSDOT database (NYSDOT 2006). The NBI includes basic information for U.S. bridges, such as 'Bridge Identification,' 'Structure type and material,' 'Age and service,' 'Classification,' 'Bridge condition,' 'Bridge geometry,' 'Inspection,' 'Proposed improvement,' 'Appraisal,' 'Navigation,' 'Load rating and posting,' and other information specific to a given bridge. The NBI offers basic information and condition data about existing bridges, but does not include failure or damage information. The NYSDOT bridge failure database includes failure date, type, cause, as well as number of dead and injured. It also includes some identity and location information. However, neither of these information sources contain the necessary quantitative information needed for further improvement of current bridge design specifications. One very important issue is that there is no standard to describe damage or failure for computer modeling purposes. In summary, all of the above sources provide useful information, but are insufficient to accomplish the objectives of bridge damage modeling. Only some limited reports and publications that deal with studies of specific bridges are helpful in this regard. Therefore, the establishment of a database of damaged bridges (DDB) is proposed. The DDB will integrate current existing bridge information sources to include the following:

1) Bridge design information (design documents, construction, drawings, etc.).
2) Environmental (geographical and weather) conditions.
3) Hazards information and traffic conditions.
4) Bridge damage and loss information (damage positions and damage modes, etc.) and economic and environmental impacts.

1.1 Damage Database of Bridges (DDB) Background: Damaged Bridges in the U.S.

1.1.1 Damaged Bridges

In the past century, many notable catastrophic highway bridge failures have occurred. These failures have resulted in both serious casualties and large economic losses.

The most well-known bridge failures, including the Ashtabula bridge (Ohio, 1876) (Peet 1877), the Tacoma Narrows Bridge (Tacoma, Washington, 1940) (Billah and Scanlan 1991), and the I-35W Mississippi River bridge (Minneapolis, MN, 2007) (Holt and Hartmann 2008; Hao 2009), occurred because of design or material defects that have been obviated by contemporary practice. However, better design and engineering practice cannot completely eliminate the risk of bridge collapses. Important examples in recent decades include the failures of the Schoharie Creek bridge on the New York Thruway in 1987 during intense rain (NTSB 1988; Storey and Delatte 2003) and the San-Francisco-Oakland Bay Bridge in 1989 during the Loma Prieta earthquake (Semans and Zelinski 1981) (National Geophysical Data Center 1990). Several other failures occurred during flooding on the Mississippi River in the 1990s, and Hurricane Katrina and related flooding in 2005 (NIST 2006). Table 1-1 presents a list of several major bridge failures in the U.S.

Table 1-1 Selected Bridge Failures in the United States to Indicate the Various Causes of Bridge Failures

Year	Description of Bridge Collapse	Bridge Age (years)	Primary Cause (Hazard)	Lessons Learned
1867	Collapse of **Ashtabula bridge** in northeastern Ohio. 165 feet of bridge fell. 92 were killed or died later from injuries**.**	2	Design/ Material Defect	Braces undersized and material defect of iron
1940	Catastrophic collapse of the **Tacoma Narrows** suspension bridge in Washington State. Video: http://www.youtube.com/watch?v=3mclp9QmCGs	< 1	Wind	Importance of harmonics / resonance vibration
1967	Collapse of the 41-year-old **Silver** (suspension) **Bridge** across the Ohio River at Point Pleasant, WV Video: http://www.wvculture.org/history/av.html	39	Steel Corrosion & Fatigue	Need for an inspection program
1980	**Sunshine Skyway Bridge** near St. Petersburg, FL, 1261 feet of bridge fell.	10	Vessel Collision	Need to design & armor piers to protect against ship collision
1983	**Mianus River Bridge** on Interstate 95 in Connecticut. A 100-foot span fell.	29	Inspection	Pin & Hanger, Redundancy, Corrosion
1987	Total collapse of Interstate 90 **Schoharie Creek Bridge,** NY Summary Report: http://www.eng.uab.edu/cee/faculty/ndelatte/case_studies_project/Schoharie.htm	33	Scour	Need for rigorous inspection and maintenance
1989	**San Francisco-Oakland Bay Bridge** CA, Collapse Video: http://www.youtube.com/watch?v=AFwJR04qBys and http://www.youtube.com/watch?v=7Q0_Z-9839c	53	Earth-quake	Merits of performance based design
1996	**Walnut Street Bridge** Harrisburg, PA, two of seven western spans fell. Video: **http://www.youtube.com/watch?v=6DxG9yOS1dQ**	106	Scour and Ice	
2004	Interstate 10 Bridge, **Escambia Bay,** FL, 3300 feet collapsed. Summary Report: http://www.southalabama.edu/usacterec/ivanimpact.pdf	~25	Hurricane Ivan	Need to quantify wave force
2007	**I-35W in Minneapolis,** MN 13 fatalities Video: http://www.youtube.com/watch/?v=nerQhIyOwxM	40	Design Error	Gusset plate undersized

A damaged bridge database prepared by the New York State Department of Transportation (NYSDOT) documents bridge failures due to different causes (from 1876 to 2005) and is shown in Figure 1-1.

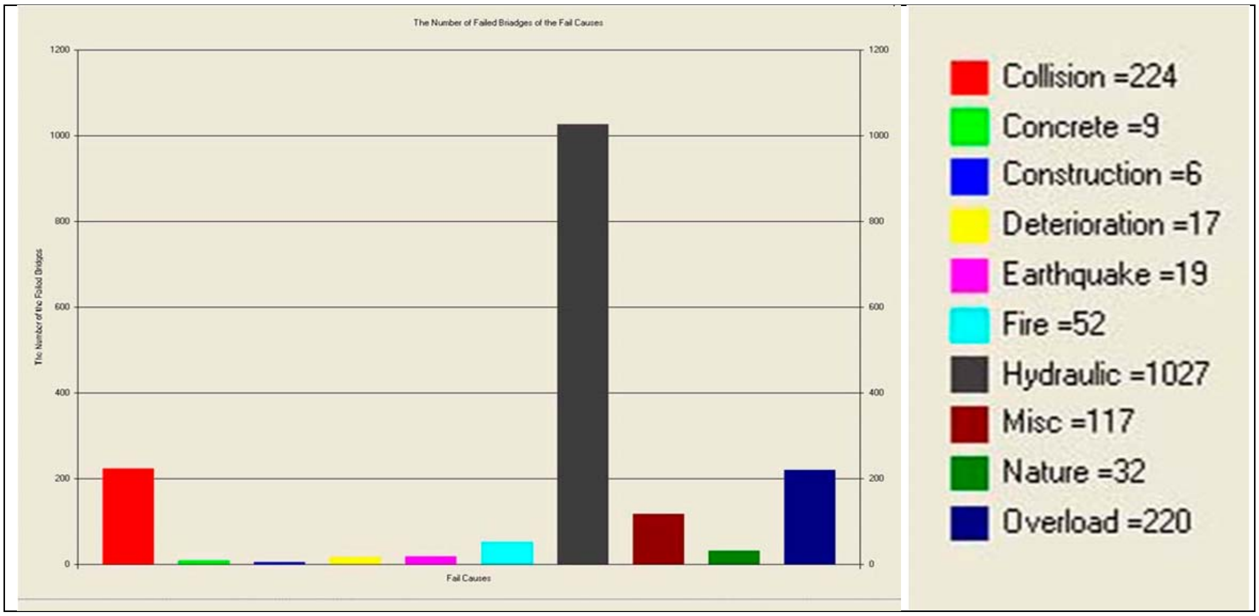

Figure 1-1 Bridge failures by cause: 1876-2005

This database suggests that most bridge failures were the result of extreme events (natural hazards), and most were hydraulic.

Table 1-2 (taken from Wardhana and Hadipriono, 2003) lists both internal (resistance-side) causes and external (load-side) causes. The failures that can be readily labeled external (shown in italics in Table 1-2) may be summarized as follows: hydraulic, 52.88%; collision, 11.73%; overload, 8.75%; earthquake, 3.38%; fire, 3.18%; ice, 1.99%; and storm/hurricane/tsunami, 0.40%. In summary, just over 82% of bridge failures (plus additional percentages from categories labeled "miscellaneous" or "soils") can be attributed to external events.

A more recent study on bridge failures in the U.S. from 1980 to 2012 shows similar results (Lee 2013a). The extreme events, such as hydraulic, collision, overload, fire, wind, earthquake, etc., account for about 88% of all the bridge failures in U.S. A list is provided in Table 1-3.

Table 1-2 Type and Number of Bridge Failure Causes

Failure causes and events	Number of occurrences	Percentage of total
Hydraulic	*266*	*52.88 %*
Flood	*165*	*32.80 %*
Scour	*78*	*15.51 %*
Debris	*16*	*3.18 %*
Drift	*2*	*0.40 %*
Others	*5*	*0.99 %*
Collision	*59*	*11.73 %*
Auto/truck	*14*	*2.78 %*
Barge/ship/tanker	*10*	*1.99 %*
Train	*3*	*0.60 %*
Other	*32*	*6.36 %*
Overload	*44*	*8.75 %*
Deterioration	43	8.55 %
General	22	4.37 %
Steel deterioration	14	2.78 %
Steel-corrosion	6	1.19 %
Concrete-corrosion	1	0.20 %
Fire	*16*	*3.18 %*
Construction	13	2.58 %
Ice	*10*	*1.99 %*
Earthquake	*17*	*3.38 %*
Fatigue-steel	5	0.99 %
Design	3	0.60 %
Soil*	3	0.60 %
Storm/hurricane/tsunami	*2*	*0.40 %*
Miscellaneous/other*	22	4.37 %
TOTAL	503	100.00 %

(Source: Wardhana and Hadipriono, 2003)
Note: Italics indicates causes due to external events; Asterisk (*) indicates uncertainty whether cause was an external event.

Table 1-3 Causes of Bridge Failures in U.S., 1980-2012

Cause			Percentage					
			2000-2012	1990-2000	1980-1990			
External causes	Hydraulic	Flood	4%	15%	10%	28%	47%	88%
		Scour	5%	9%	5%	19%		
	Collision		5%	5%	5%	15%		
	Overload		3%	3%	6%	13%		
	Fire		1%	1%	1%	3%		
	Earthquake		0%	1%	1%	2%		
	Wind		1%	1%	0%	2%		
	Environmental Degradation		2%	2%	2%	7%		
Internal causes	Design, Construction, Material, etc.		3%	3%	5%	11%		11%
Other & Misc.	-		-	-	-	-		1%
Total	-		24%	39%	36%	-		100%
(Source: Lee et al., 2013a)								

Although not every bridge collapse captures national headlines, they unfortunately occur on a fairly regular basis. Several organizations, such as the New York State Department of Transportation, already track information about bridge failures. Briaud reports that 1,500 bridges collapsed in the U.S. between 1966 and 2005 (NIST 2006); (NYSDOT 2006). From a review of these basic datasets, it appears that in the U.S., there is an average of about three failures every month. This generates an abundance of important data that is available for more detailed analysis.

Although the above information suggests that bridges damaged by extreme events have a significantly higher rate of occurrence, there are issues that require further clarification. For example, overload can be caused by either strong external load (e.g., earthquake ground accelerations greater than the design values stipulated by the specifications) or internal causes (e.g., design error). In general, the causes of bridge failures may not be clearly determined because they occur in complex interactions among the resistance and load effect. More often than not, bridge failures may be the result of "cascading" events due to consequent load effects and combined load and resistance effects. To understand whether failures are mainly attributable to excess loads is important for establishing safety measures in design. Forensic study is needed to quantitatively establish the desired safety margins for use in design specifications.

Bridge damage/failures due to all causes are important issues in bridge safety considerations. The current AASHTO LRFD bridge design specification (AASHTO 2012) is a reliability-based design approach with a sensible way to address the issue of bridge safety. This LRFD approach includes strength and service limit states considering frequent loads such as dead load, live load and wind load; it also includes extreme event limit states for natural hazards like earthquake, flood, ice flow, and vessel collision, etc. However, the extreme event limit states are not fully reliability-based. In recent years, many studies have been devoted to combining frequent non-extreme loads with infrequent extreme loads (Borges and Castanheta. 1972; Wen 1977; Turkstra and Madsen 1980; Ghosn et al. 2003; Liang and Lee 2012; Lee et al. 2013b; Liang and Lee 2013).

Quantitative information about bridge collapses in a convenient to use database would be very helpful not only for forensic investigations (lessons learned in quantitative forms), but also for future research development. However, establishing a comprehensive database system for bridge collapses under extreme hazards is a complicated task.

To achieve the short term objective, bridge information will be collected for bridges that have been destroyed by selected natural hazards such as flood, earthquake, wind, and vessel collision.

1.1.2 Existing Database

Some important bridge information is available in various existing databases and other resources such as NBI, NBIS, PONTIS, and the NYSDOT failed bridge database are briefly reviewed in this section. These databases are important and useful, but they do not satisfy the objectives of developing bridge damage models.

1: National Bridge Inventory (NBI) (FHWA 2013)**:** The NBI is a comprehensive collection of information covering over 600,000 of the Nation's bridges located on public roads, including Interstate Highways, U.S. highways, State and County roads, as well as publicly-accessible bridges on Federal lands.

The bridge inventory is developed to establish a unified database for bridges including the identification information, bridge types and specifications, operational conditions, and bridge data including geometric data, functional description, inspection data, etc. Identification information provides a unique designation of the bridge location, classifies the type of routes carried out on and/or under the structure, and situates the bridge within the spatial location. Bridge type and specifications classify the type of the bridge. This part provides pre-defined standard categories to classify the bridges. It also specifies the material of the bridge components, deck and deck surface. Operational conditions provide information about the age of the structure as well as construction year, rehabilitation year, type of services and traffic carried over and/or under the structure, number of lanes over and/or under the bridge, average daily traffic, average daily truck traffic, and information regarding to bypasses and detours. Furthermore, the bridge inventory contains information regarding inspection data, ratings assigned by inspectors, and appraisal results. In summary, the NBI is used to manage the bridge system; however, the information is not sufficient to develop a case study of bridge damage.

2: National Bridge Inspection Standards (NBIS) (FHWA 2004)**:** The FHWA established National Bridge Inspection Standards for the safety inspection and evaluation of highway bridges. Each State is required to conduct periodic inspections of all bridges subject to the NBIS, prepare and maintain a current inventory of these structures, and report the data to the FHWA using the procedures and format outlined in the “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.”

These standards are not intended to collect information about the historical performance of bridges to improve bridge design or retrofit practice. Instead, the focus of the program is on intermittent visual condition inspections that provide a qualitative assessment of the extent of damage. It is only used for inspections.

After evaluation of the inspection data, the FHWA provides States with a list of bridges that are eligible for replacement or rehabilitation. The FHWA uses the data to submit a required biannual report to Congress on the status of the Nation's bridges, publish an Annual Materials Report on New Bridge Construction and Bridge Rehabilitation in the Federal Register, and to apportion funding.

3: AASHTOware® Bridge Management (formerly known as Pontis) (FHWA 2002)**:** AASHTOware® Bridge Management (formerly known as Pontis) is a comprehensive bridge management system software tool that plays a vital role in a transportation agency's asset management process. It can assist agencies in allocating scarce resources to preserve existing infrastructure investments, ensure safety and maintain mobility. AASHTOware® Bridge Management stores inventory and inspection information about bridges, culverts and other structures in a relational database that supports an innovative set of modeling, analysis and reporting tools to facilitate project, budget and program development. It also helps formulate network-wide preservation and improvement policies for use in evaluating the needs of each structure in a network; and makes project recommendations to include in an agency's capital plan. It also analyzes the impact of different project alternatives on the performance of individual structures or a network of structures.

A number of States have adopted and implemented the AASHTOWare® Bridge Management System, or a similar system with advanced asset management decision making capabilities. Some States augmented the NBI data used in advanced bridge management systems by collecting element level bridge data. Even with these bridge management tools and data, however, there remain many unknowns about the performance and degradation of structures and materials over time, and the effectiveness of maintenance, repair, and rehabilitation strategies for a given component or a complete bridge system. In addition, with the recent move to higher performance materials and advanced structural systems, high-level, long-term performance and durability are assumed, but not demonstrated, at this time.

4: NYSDOT failed bridge database (NYSDOT 2006)**:** The NYSDOT failed bridge database collected information about bridges that failed from 1896 to 2005, including information about the location, failure cause, and collapse/damage. It can be used for statistical analyses. However, it does not include detailed information about the damage/failed components, and only has data contributed by some states on a voluntary basis so it is not suitable for use in a case study.

Figure 1-2 shows the number of damaged bridges in different states throughout the U.S. (note that this figure was generated from the DDB software).

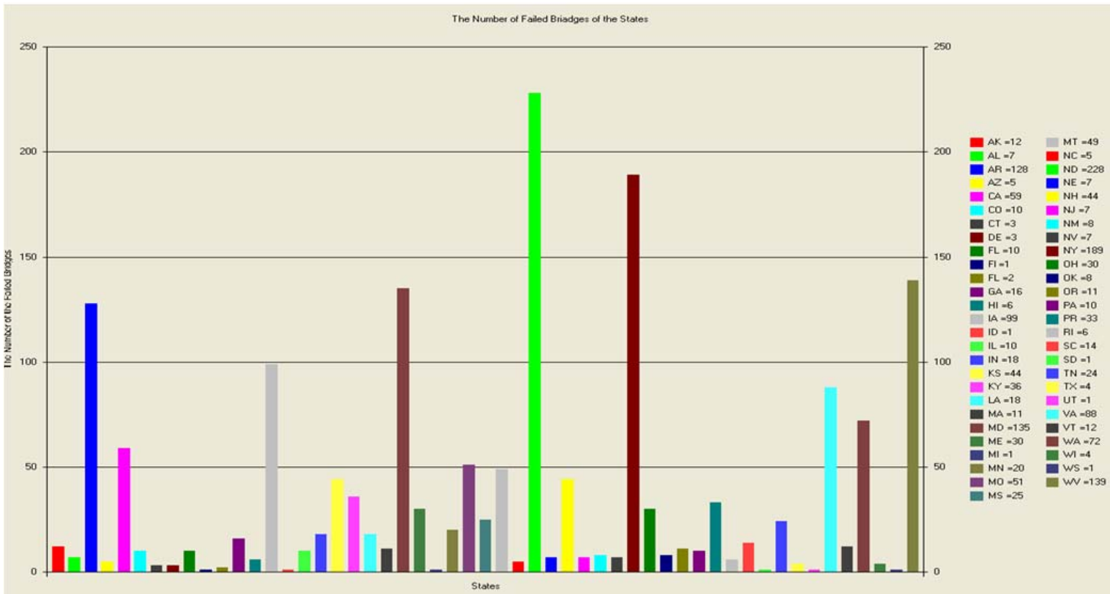

Figure 1-2 Number of damaged bridges by state

5: Other internet data for bridge collapses: There are other internet data created mainly for the purpose of statistical analyses and providing information to the public. They contain minimum information for damage modeling of bridges and their validity cannot be confirmed. An example of this type of available information is the bridge forum website http://www.bridgeforum.com/dir/collapse/; see Figure 1-3.

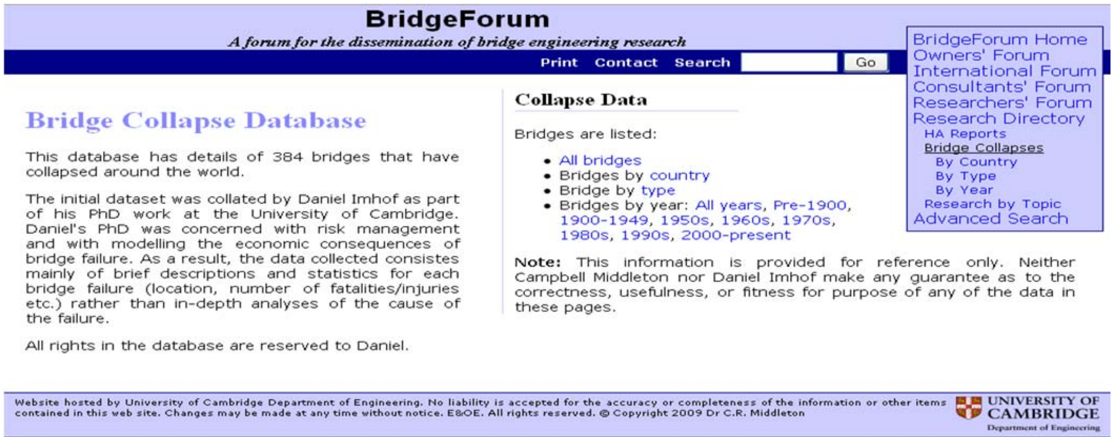

Figure 1-3 Website Information

In addition, there are several other bridge inventory systems created to satisfy specific purposes. The California Department of Transportation (Caltrans) Bridge Inspection Records Information System (BIRIS), and Structure Maintenance Automated Report Transmittal system (SMART) are representative systems. These collections have valuable information for investigations of past bridge collapses, but they are not convenient to search and obtain the required information. Specific accident reports related to transportation (NTSB 1988; NTSB 2002), recorded and published by NTSB (National Transportation Safety Board), provide useful data directly related to highway bridge collapses. Caltrans has published several seismic reports about the bridges damaged during earthquake events, but again, the information is not convenient for direct use in quantitative analyses (Semans and Zelinski 1981; Storlie and Semans 1984).

After reviewing all the available databases, MCEER researchers (Lee et al., 2013a) recently summarized 1,062 cases of bridge damage and failures in the U.S. due to internal or external causes. A dataset is generated in spreadsheet format that includes general bridge geometrical and structural information, detailed failure information, and other pertinent information. However, not all the bridge failures provide sufficient information that can be used for further improvement of current bridge design specification; e.g., providing the basis for the establishment of multi-hazard load and resistance factor design (MH-LRFD), a targeted long term goal toward continued updating of the AASHTO LRFD.

All this available information will be significant and useful if it can be collected in a consistent format and well organized. Therefore, a database for damaged bridges (DDB) is developed and established in this project in a format that is both easy to use and easy to add bridge damage information in the future.

1.1.3 FHWA Long-Term Bridge Performance (LTBP) Program

To overcome current challenges and foster the next generation of bridge performance and bridge management systems, the Federal Highway Administration's (FHWA's) Office of Infrastructure Research and Development launched the Long Term Bridge Performance (LTBP) Program in April 2008. The LTBP program is a major new strategic initiative designated as a flagship research project (FHWA 2007). It is intended to be a minimum of a 20-year undertaking, with the global objective of collecting quality scientific data from the Nation's highway bridges. The data and information collected in this program will provide a more detailed and timely picture of bridge health, improve knowledge of bridge performance, and ultimately promote the safety, mobility, longevity, and reliability of the Nation's highway transportation assets.

The data collected can also be used to study the deterioration and durability of bridges and the impact of maintenance and repair. Researchers anticipate that the program will provide a better understanding of bridge deterioration process, including the effects of corrosion, fatigue, environmental conditions and loadings.

The data collected through the LTBP program, and the subsequent data analysis, will lead to:

- Improved knowledge of bridge performance
- Advances in deterioration and predictive models
- Deterioration models that can simulate interactions between pavement, bridges, and traffic
- Effective use of life cycle cost analysis
- Improved inspection/condition information through NDE and structural health monitoring; and the fostering of technology for assessment of critical but inaccessible bridge elements and components
- Support for development of improved design methods and maintenance/bridge preservation practices

- Quantification of the effectiveness of various maintenance, repair, and rehabilitation strategies
- Improvement of the operational performance of bridges with the potential to reduce congestion, delay, and crashes
- Fostering of the next generation of bridge and bridge management systems
- Contribute knowledge for national policies

If the LTBP program can also include the documentation of damaged bridge information, such as the information included in the DDB, it will be further enriched. Thus the DDB considered herein should be developed and prepared to be merged into the LTBP effort in the future.

1.2 Necessity for a New Database System for Bridge Damage

1.2.1 Lessons Learned from Bridge Failures

One important issue to be addressed before better collapse-resistant bridges can be achieved is to develop a better understanding of the fundamental causes of failures that have occurred in the past. Though there are historical accounts and a few forensic studies of the worst failures, there is currently no central repository for the detailed and specific data about the load effects of extreme hazards. Likewise, information about the response of the bridge during an extreme event such as the forces carried by critical structural components is not regularly available and recorded. Furthermore, there are no accepted criteria to define or describe damage to different types of bridges. Thus, a uniform DDB is needed to enable further statistical analysis, case studies, and other similar efforts.

1.2.2 Value of Forensic Studies

Due to the difficulties in anticipating all collapse scenarios that might occur over the service life of a bridge, it is logical to draw insight from the historical performance of the bridge population as a whole. A better understanding of past failure mechanisms can contribute directly to the development of an improved bridge design specification by comparing the extreme hazard load effects on bridges and structural resistance, and improving the extreme event loading calibration.

Code developers currently encounter a dilemma of protecting a bridge from multiple hazards simultaneously such that the hazards are considered equitably yet the design is optimized to safeguard life, minimize damage, and be cost effective. Similar difficulties exist with regard to the management of existing bridges.

The U.S. needs to invest in the research and information systems that will help engineers to appropriately reduce the loss due to future disasters. Researchers should continue to inspect the progressive failure of entire bridge systems, and further develop computer modeling of nonlinear dynamics to simulate the bridge failure processes. Coordinating with economists and risk analysts, a better understanding of methods to minimize costs during the life cycle of a bridge can be achieved.

In general, for any specific case of failure, a forensic study is needed to establish whether a failed bridge did or did not fulfill required codes, design specifications, and expectations of the profession; whether it had been given proper maintenance; and whether by accepted standard bridge problems should have been recognized and the bridge closed or retrofitted. Forensic autopsies of damaged bridges can lead to:

- Better understanding and improved knowledge of MH bridge performance
- Advances in predictive MH damaged models
- Improved life-cycle cost analysis with MH
- Improved MH design methods for bridge codes in the future
- Improvements in the effectiveness of the NBI and Pontis
- Improved highway bridge systems model in Hazus-Multi Hazard, developed by the Federal Emergency Management Agency (FEMA 1997) (damage state calculation model, direct economic loss model, etc.)

1.2.3 Benefits of the DDB

Lee et al. (2013) proposed a procedure for developing LRFD bridge design specification, as shown in Figure 1-4.

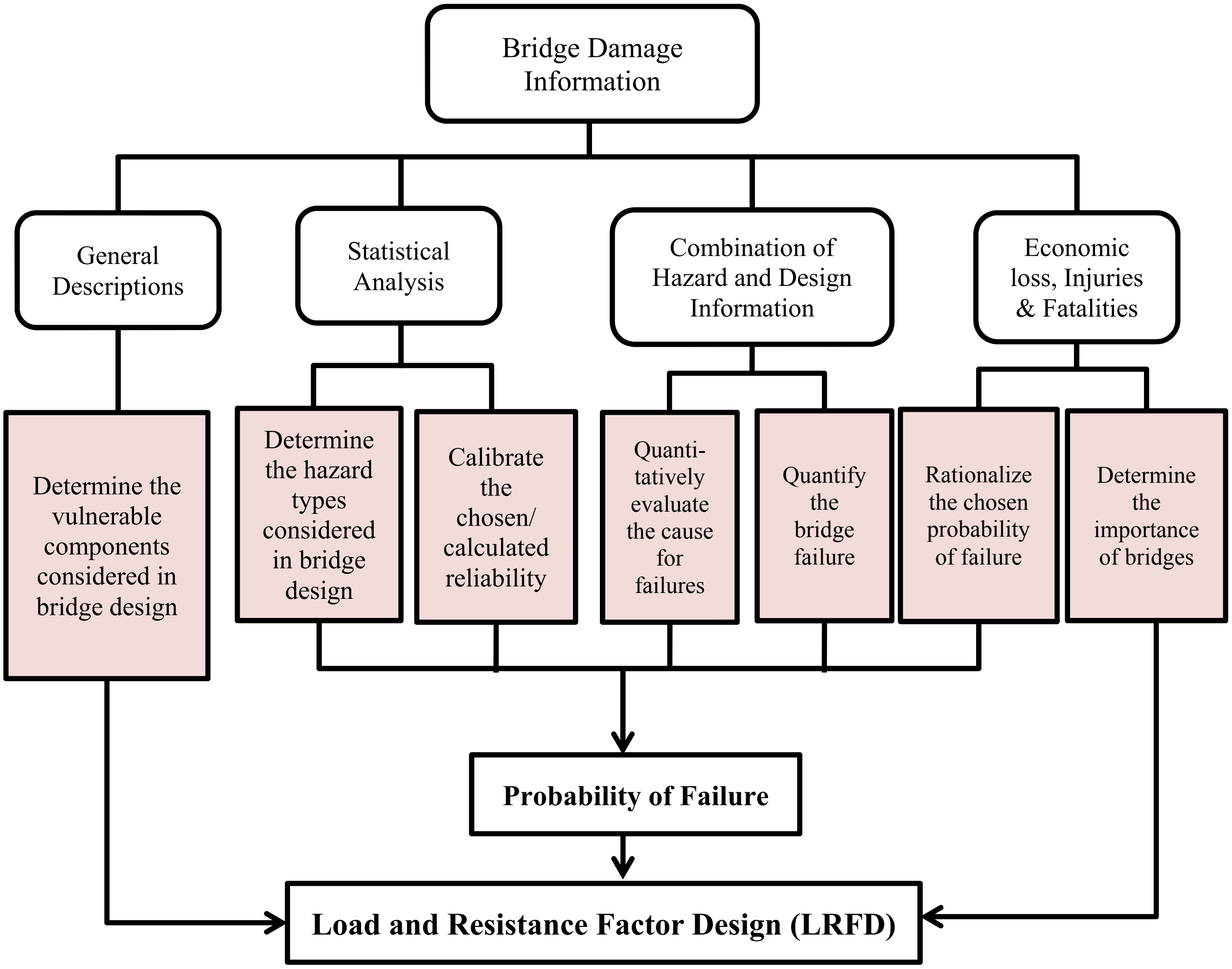

Figure 1-4 Development of Load and Resistance Factor Design (LRFD)

In fact, the establishment of the proposed DDB will play an important role in the development of the next generation LRFD bridge design specification, as shown in Figure 1-5. Detailed benefits are as follows:

- The data and information collected in the DDB will provide more detailed and high-quality quantitative damage pictures and documents of the damaged bridge, to improve knowledge of the bridge performance, develop new models, and ultimately promote safety and reliability.
- The DDB can be used for a variety of purposes to better understand hazards, bridge damage and fragility, post-hazard traffic state, transportation travel demand, economic loss, and the impacts of maintenance, repair or retrofit.

- The information in the DDB can help to quantitatively validate the results of MH-LRFD design principles and methodologies that are currently being developed (Lee et al. 2013).
- The DDB can offer information that bridge owners need for decision making regarding multi-hazards and life-cycle costs.
- The collection and cataloging of failure and performance data also provides benefits for bridge management. With sufficient data, the performance of particular bridge components or a structure as a whole can be plotted versus time. These deterioration curves can be used as a tool for allocation of maintenance resources, to program bridge replacements, or used in conjunction with a structural health monitoring protocol to keep close tabs on a significant bridge so that unexpected changes in condition can be anticipated or immediately detected.

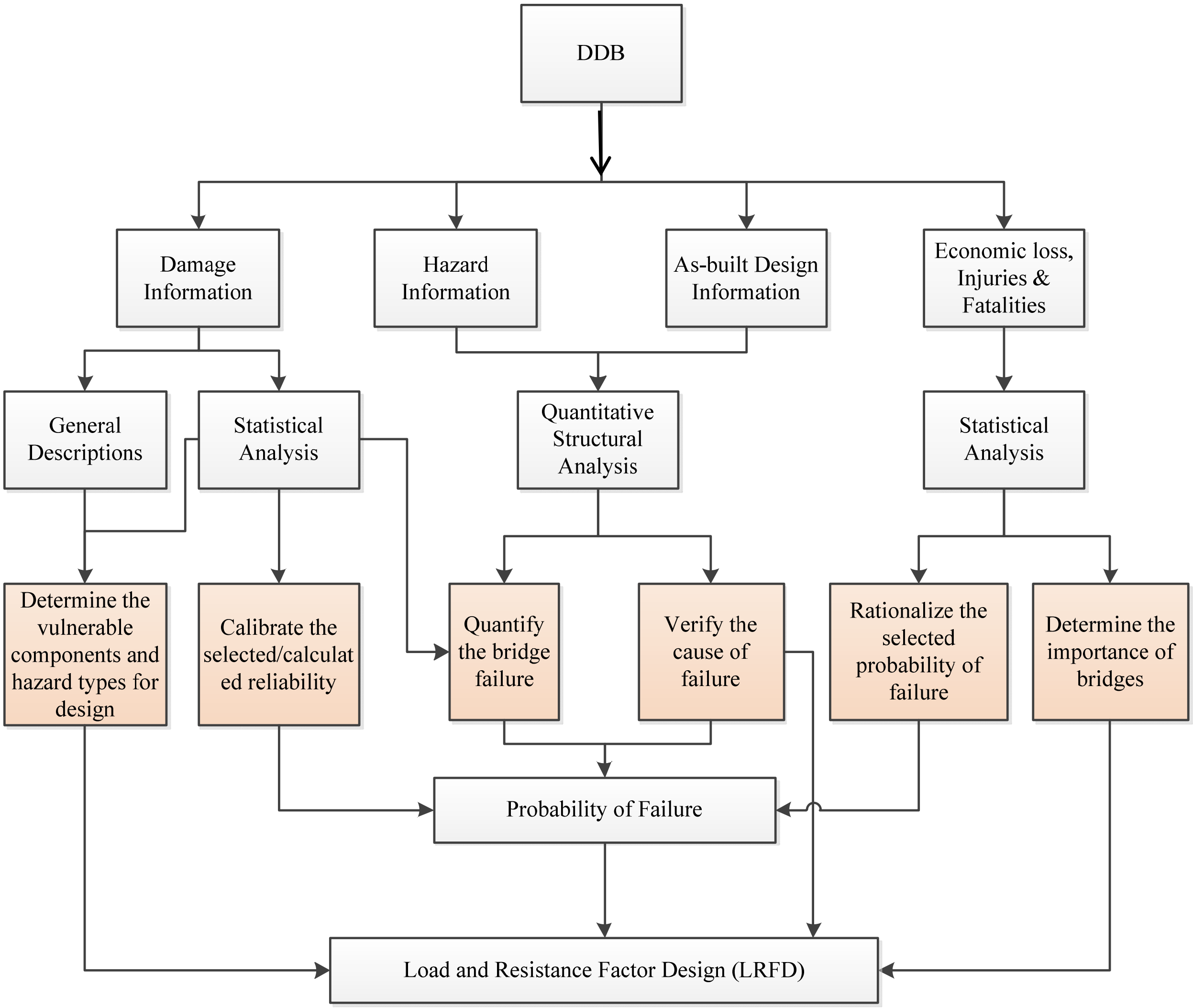

Figure 1-5 Role of DDB in Development of LRFD

SECTION 2

DATABASE OF DAMAGED BRIDGES (DDB) COMPOSITION

2.1 Data Collected in the DDB

As mentioned in Section 1, the database of damaged bridges (DDB) should include the collection of four types of information: hazard information, original design and construction information, failure information and other information (e.g., economic losses and casualties). Much of this information will be saved as graphic files or document files in the proposed DDB. The database will keep these types of files available for users to access.

1. Hazard and Bridge Environment Information

a) Bridge hazards can be divided into three categories, as shown in Table 2-1.

Table 2-1 Bridge Hazard Category

Number	Hazard Category
I	Natural Hazards (e.g., flooding, scour, earthquake, wind)
II	Man-made – Unintentional (e.g., condition related, accidents such as collisions, learning experiences, deficient designs, lack of maintenance, lack of enforcement)
III	Man-made – Intentional (i.e. fanatical acts of terrorism)

In this report, only hazards in Category I and part of Category II are considered.

b) Design for bridges subjected to multi-hazards should consider three cases:

- Concurrent hazards, i.e., assuming that two or more hazards will occur and simultaneously impact an infrastructure system;
- Cascading events or hazards act in a certain consequence, i.e., structures that have sustained damage from one event may need to resist additional loads caused by a subsequent event prior to any repairs being carried out.

- All hazards should be considered by an appropriate approach to optimize the design of structures to meet the requirements of specifications while minimizing life-cycle costs.

c) The environment information needs to be collected together with the hazard information, e.g., the magnitude of the earthquake, the ground information of the bridge site, etc., are necessary when bridges are subjected to earthquake hazards.

Table 2-2 shows the severity measures for different types of extreme events.

Table 2-2 Severity Measures for Extreme Events

Hazard Type	Measures for severity
Blast (Excludes explosively formed penetrating devices)	Charge weight Standoff distance Wave front
Earthquake	Peak ground acceleration Peak ground velocity Peak ground displacement Movement direction Movement frequency or period duration Surface rupture Liquefaction potential
Fire	Fire size Peak rate of heat release Rate of fire growth
Flood (also see Scour)	Discharge as in cubic meters/sec Water level Flow velocity Lateral force of waves Buoyant uplift Debris impact
Scour	Change in stream bed elevation Stream bed contraction Vortexes and flow acceleration at pier Depth of scour revealed at river cross section at pier (compared to cross-sectional benchmark, such as a similar part of river, or site's pre-construction cross-section)
Wind	Max wind speed (i.e., over 50 years) Wind pressure, positive and negative Peak gust (function of mean wind speed, gust duration, surface roughness, height above ground)

2. Bridge Design Information

a) To establish analytical model(s), detailed design information about the bridge is essential.
b) Design drawings (blueprints or AutoCAD file, including the general layout and design details).
c) Construction document and drawings.
d) Special designs for different hazards, e.g., the isolation device and the soil condition of the bridge subjected to earthquakes or the protection systems of the pier to avoid the vessel collision.

3. Bridge Damage Information

For the bridge damage information, different components of the bridges and different failure modes should be considered and collected.

Possible Failure Modes

There are numerous scenarios that could undermine the integrity of a bridge and its ability to carry traffic. Below is a partial list of different failure modes:

a) Girder unseating because of the loss of support(s) at a pier due to:
    a) Undermining of the foundation from scour
    b) Loss of a pier due to vehicular or vessel collision
    c) Plastic hinging formed during earthquakes
    d) Inadequate width of seating
    e) Toppled bearing
b) Severe deformation of one or more primary members due to:
    a) Impact from vehicular or vessel collision
    b) Fire underneath (usually resulting from spilt fuel from a vehicular collision)
    c) Earthquake
c) Excessive tipping of an abutment or pier due to:
    a) Scour
    b) Liquefaction
    c) Vessel collision

d) Excessive lateral displacement due to:
    a) Wave force and/or flooding
    b) Earthquake loading
e) Structural failure of a member due to:
    a) Inadequate design for daily traffic loads
    b) Brittle fracture resulting from fatigue
    c) Ductile fracture from overload
    d) Corrosion
    e) Localized deterioration
    f) Excessively localized loading
    g) Lack of freedom for movement due to corrosion
    h) Unintentional displacement of a member (e.g., a failed pin in a pin and hanger assembly)
    i) Loss of pre-stressing in a P/S beam which is uplifted due to buoyancy forces

Each single extreme event may cause different damage/failure to bridge structures. For example, an earthquake can cause failure of bridge superstructures or substructures, individually or simultaneously.

Table 2-3 summarizes some damage modes of bridges under earthquake(s).

Table 2-3 Damage modes of bridges under earthquake(s)

Name of component		Failure models	Annotation
Superstructures	Beam or girder	Unseating (Loss of span)	Collapse
		Local collision damage	Local damage
	Steel truss	Local buckling or yielding	Local damage, may be collapse
Substructures	Pier or column	Moment damage, shear damage, moment and shear damage, joint damage, Inadequate ductility capacity	Local damage, may be collapse
	Abutment	Wing wall damage, back wall damage, inclination of abutments Failure of shear keys at abutments etc.	Local damage, may be collapse
	Bearing	Bearings damage, anchor bolt damage etc.	Local damage, may be collapse
	Foundation (footing)	Pile damage, footing damage	Local damage, may be collapse
Other components	Expansion joints	Expansion joints collision damage	Local damage
	Shear key	Shear key damage	Local damage
	Bumper block	Bumper damage	Local damage
	Restrainers cable	Restrainers cable fracture	Local damage

4. Other Information

In addition to the above information for hazards, bridge designs and damage, the following factors needs to be considered in information collection:

- Rating damage level
- General environmental (example: hydraulic, geology) information around the bridge and bridge network formulated in a certain area
- Detailed hazard loss information
- Regular inspection information including deterioration information
- Retrofit/ reconstruction, any specific maintenance information or changed conditions

2.2 Development of the DDB

2.2.1 General Information

A comprehensive database is developed according to the following steps:

1) Identifying the entities for the database (hazards include: Earthquake, Flood/Scour, Vessel Collision)
2) Coordinating with hazard experts for comments and suggestions on the database.
3) Searching and collecting information from various sources.
4) Creating the user interface to facilitate using the information.

2.2.2 Working Platform

The DDB is created using Microsoft Access as a data storage tool. When the database becomes too large, it can be updated to SQL server or Oracle.

The user interface is created to use the database in different ways, such as to obtain statistical information about damaged bridges or searching the information available. Microsoft C#.net was used as a Windows program. It can be recoded to a website program.

DDB structure -- Data has been designed to be collected in the database.
The **DDB** includes three Access database files:

HWNBI_BRIDGE: NBI

NYSDOT_Bridge_Failure: NYSDOT failed bridge database

FailedBridge: This is the most important part of the DDB. It includes the following basic information data tables:

- Basic bridge information (location, type, material, length, structure number, etc.)
- Extreme event information (time, location, causes, etc.)
- Event loss information
- General information for the event

- Design information of the bridge
- Damage information of the bridge
- Hazard:
  1. Earthquake
     - i Bridge seismic design information
     - ii Site soil changing
     - iii General earthquake information
     - iv Earthquake records
  2. Flood/scour
     - i Pier design related to the scour
     - ii Abutment design related to the scour
     - iii Bridge design related to the flood
     - iv Scour and hydraulic information around the bridge site, pier and abutment
  3. Vessel collision (CV)
     - i Vessel information
     - ii Bridge navigation information
     - iii Bridge site hydraulic information
     - iv Impact information
     - v Weather information
     - vi Protection information
  4. Fire
     - i Fire information
  5. Truck collision
     - i Truck information
     - ii I impact information
- Case study

Because much of the bridge damage information is in the form of pictures/graphs, different directories are created to save these files and list the file names in the information tables. The basic structure of the DDB is shown in Figure 2-1 and the organization is shown in Figure 2-2.

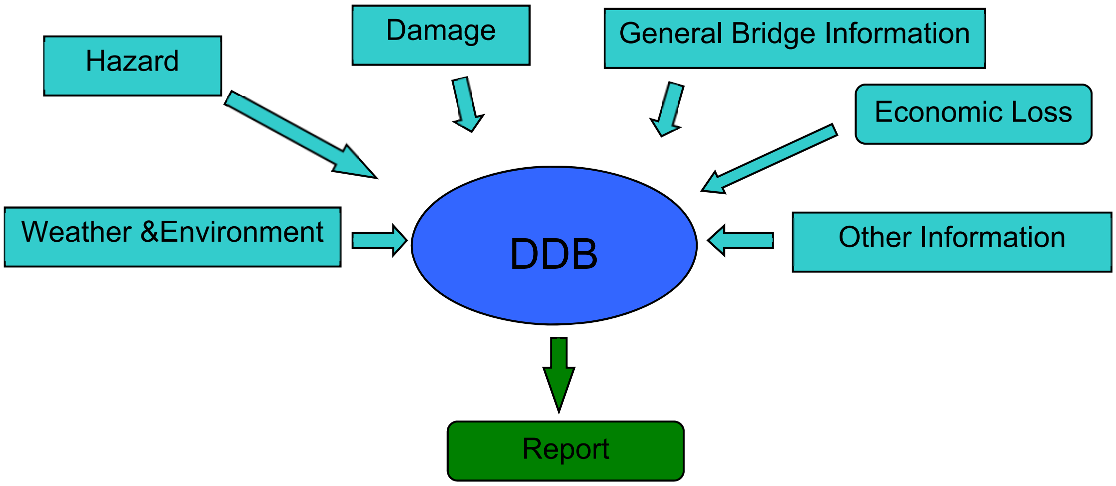

Figure 2-1 Structure of the DDB

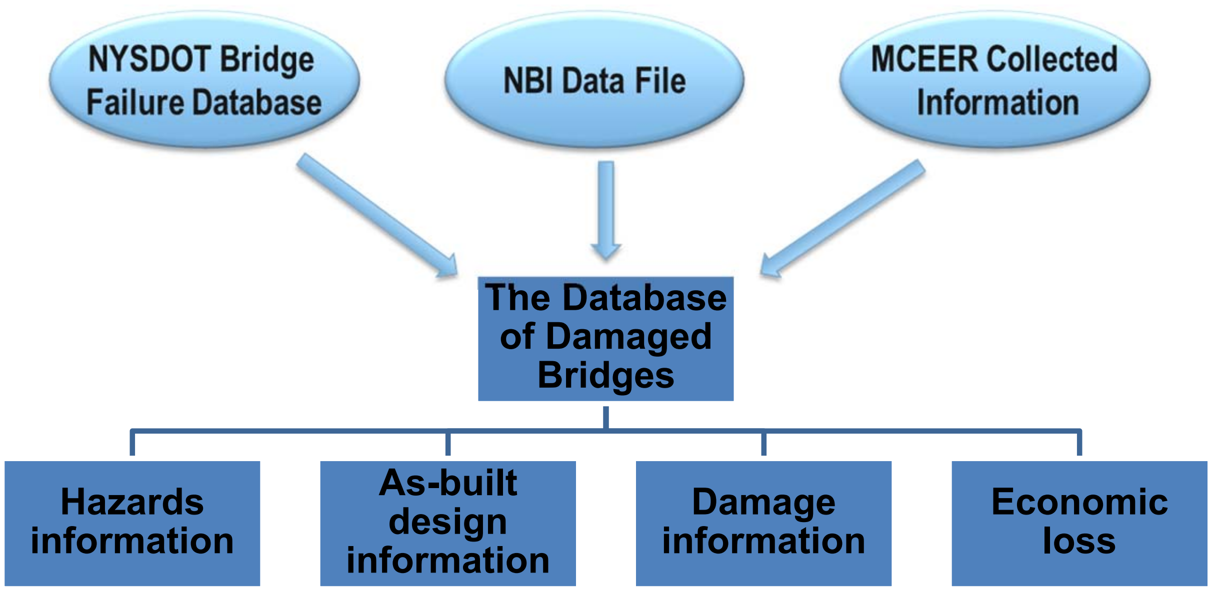

Figure 2-2 Organization of the DDB

Due to time and data resource limitations, only one bridge damaged by flood/scour, one bridge damaged by vessel collision and several bridges damaged by earthquake are shown for demonstration purposes. In fact, the data collection is the most important and most difficult part of developing the DDB. All the benefits of the DDB depend on the quantity of bridge information that will be collected.

Some challenges during data collection for the damaged bridge database are listed below:

- Detailed information is difficult to collect, especially the design information. Without a detailed design profile, the data collected may not be sufficient for use in case studies. It is possible to link the current DDB with State DOT or FHWA information sources to obtain the design information for bridges.
- The collected data is not ready for use in reliability calculations; e.g., for scour, only the scour size and depth have been obtained. The river hydraulic information has not been collected, which is needed to be able to estimate the scour information. Thus, the information collected can only be used for case study purposes and not for reliability analysis. In the future, more details may become available and the data can be used for reliability analysis.
- In some cases, information cannot be released due to litigation resulting from failures that may take many years to conclude.

2.2.3 DDB Data Resources

Figure 2-3 shows the data resources used for the DDB. Some of these resources are as follows:

- Data from NBI (FHWA 2013)
- NYSDOT bridge failure database (NYSDOT 2006)
- Bridge damage/failure event information from reports, journals, websites and other sources, such as reports from Peet 1877; Semans and Zelinski 1981; Storlie and Semans 1984; NTSB 1988; National Geophysical Data Center 1990; Billah and Scanlan 1991; Buckle 1994; Priestley et al. 1994; Zelinski 1994; Lew et al. 1995; Landers et al. 1996; Schiff 1997; Ortega 1999; O'Connor 2000; AASHTO 2001; Farrag and Morvant 2001; Ham and Lockwood 2002; NTSB 2002; Ghosn et al. 2003; Storey and Delatte 2003; Sutcliffe 2003;

Wardhana and Hadipriono 2003; Ocean Engineering Associates 2005; Catbas et al. 2006; Cooke and Rohleder 2006; NIST 2006; Sternberg and Lee 2006; U.S. Department of Transportation Inspector General 2006; Holt and Hartmann 2008; Lee et al. 2008; Lee and Sternberg 2008; Reid 2008; Hao 2009; Lee et al., 2013a.

- Data from individuals (project collaborators) and organizations
- Hazard information and records from the USGS, Pacific Earthquake Engineering Research Center (PEER), and the National Weather Service (NWS)
  - USGS: seismic design information
  - USGS: Bridge Scour Data Management System (BSDMS)
  - PEER: earthquake records
  - National Climatic Data Center (NCDC) United States Storm and Hazard Database
- From international cooperation such as the Taiwan traffic department
- Other data that can be obtained and included in the DDB
  - Owner's supplemental inventory data and bridge history file
  - Bridge inspection reports
  - Progressive scour depth measurements
  - Structural integrity evaluations
  - Historical maintenance records
  - Bridge vulnerability assessment data

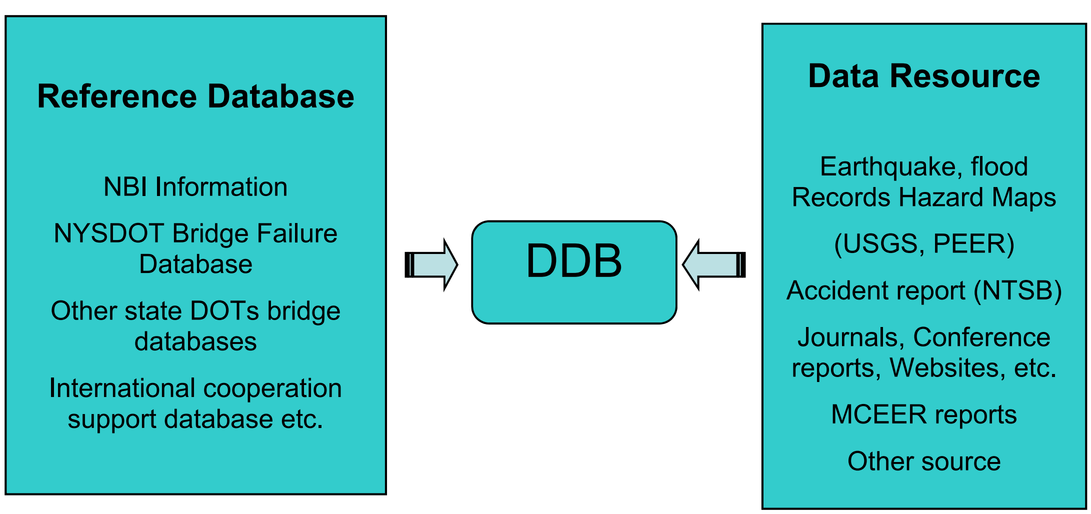

Figure 2-3 Resources used in the DDB

Since detailed information is essential for the quantitative understanding of bridge failures, an effort will be needed to assemble as much information as possible. In general, the bridge owners and the state DOTs possess the most up-to-date and accurate information, so efficient communication between them and researchers is necessary.

International experience may also prove to be beneficial, especially in countries that employ the AASHTO standard or LRFD specifications for bridge design (AASHTO 2002; FHWA 2004). For instance, the up-to-date practical experience with earthquakes and related effects such as landslides, flooding, and scour in Taiwan can be tapped to provide additional valuable data.

Some significant bridge collapses may attract public attention, but they may not reoccur for a relatively long time. Thus, if the most pertinent data about the overall bridge collapse are collected from as many sources as possible around the world, it will be much easier to obtain a correlation between possible factors and determine the potential for failure in the future.

Examples of useful data for better risk assessment of bridge collapses due to one or more hazards are:

- Structure type and material (not only steel/concrete but compressive/tensile strength, etc.)
- Element level condition ratings
- Design criteria used (e.g., if a bridge was designed and built before fatigue behavior was fully understood)
- Design detailing (especially the presence of details that are known to be undesirable)
- Proximity to traffic lanes or navigable waterways

2.2.4 User Interface

The user interface is developed so that users can conveniently access the data in the DDB. The interface should be convenient, and enable the user to retrieve information of interest. The development of the interface should include interviews with users to obtain their input and suggestions. The single bridge information interface and some simple statistical interfaces for the NBI are created in this version. For NYSDOT, some statistical graphics are included in the user interface.

This software will facilitate the search and statistical analysis of bridge failure under hazards that are necessary for case studies. A comprehensive set of menus, dialogues, tool bars, buttons and forms are supported.

The interfaces of the DDB show many types of information about the damage bridge. Users can search information from the damaged bridge identity by different means. To use the information in the database, C# has been used to code and debug the user interface program.

The DDB can be used to search information by:

a) Bridge information in NBI
b) Damaged bridge information in the NYSDOT database
c) Bridge information damaged by earthquake (EQ)
d) Related EQ information and record
e) Bridge information damaged by Vessel collision (CV)
f) Related bridge navigation information
g) Related bridge component information damaged by CV
h) Boat (Barge) information
i) Bridge information damaged by Flood/Scour (FS)
j) Hydraulic information in the bridge area
k) Related component information which damaged by FS
l) Damage information of the bridge
m) Design information of the bridge

The database user's manual is attached as Appendix A.

Users and experts will be connected to share suggestions and comments to improve the user interface and other aspects of the DDB. More time and resources will be needed to improve the current version.

2.2.5 Case Study

Detailed information from a national bridge collapse database could be used to digitally reconstruct one or more of the events using finite element analysis. This "accident reconstruction" involves identification of the hazard, its load effects and response characteristics of the "as-is" structure. The as-is condition of the structure is the bridge as designed with consideration of modifications that occurred during or subsequent to original construction. These variations from the original design may or may not be noted in the record plans or work history file. The as-is condition also takes into account any changes that have occurred over time due to repair, rehabilitation, or deterioration that may be due to corrosion or fatigue.

Only one case study example, the “Bull Creek Canyon Channel Bridge” (Todd et al., 1994) with earthquake and scour damage, has been completed and is included in this report.

2.3 Information in the Damage Database of Bridges (DDB)

2.3.1 Basic Information about the Bridges and Extreme Events

1) Event information

- Event identity
- Bridge identity
- Damage cause (event hazard type) -- Earthquake, Vessel Collision, Flood/Scour
- Event time (year, month, day and time)
- Bridge damage rating
- Replaced bridge identity of the damaged/failed bridge
- Event description
- Event information source

2) Basic bridge data

- Bridge identity
- Nation
- Location
- State code if in U.S.
- County code if in U.S.
- Structure number
- Feature- intersected
- Inventory route
- Route class
- Route direction

- Longitude
- Latitude
- Structure type (Main)
- Material
- Span number
- Approach span number
- Structure length
- Deck width (out to out)
- Length of maximum span
- Skew angle degree
- Year reconstructed
- Service type
- Service level
- Parallel bridge yes/no
- Average daily traffic (ADT)
- Year of ADT
- Built year
- Design year
- Design company
- Construction company
- Retrofit Information
- Description
- Comments/source

3) Design information

- Bridge identity
- Design components (general information, general layout, superstructure, pier/column, bearing, foundation, abutment, other)
- Information source

Minimum Design Information Required

  - Bridge layout

- Component shape, size and material
- Applicable design code

4) **Damage information**
   - Event identification
   - (Bridge identification)
   - Damage component identity
   - Damage structure type
   - Damage component type
   - Damage component
   - Damage mode
   - Damage rate
   - Information source

5) **Loss information**
   - Event identification
   - Fatality number
   - Injury number
   - Bridge loss
   - Directed loss
   - Traffic down days
   - Indirect loss
   - Other loss
   - Total loss
   - Information source

6) **Other General Information about the Event**
   - Information file
   - Information source

2.3.2 Hazard Information: Earthquake

1) Earthquake bridge design information

- Earthquake design spectrum
- Earthquake design PGA
- Earthquake design return period
- Bridge site soil type

2) Change in bridge environment information after earthquake

- Area ground change
- Area liquefaction
- Environment information

3) Earthquake information

- Name
- Epicenter (EPC) location, longitude, latitude, …
- Magnitude
- Magnitude of intensity
- Depth
- Date & time
- Duration
- Mechanism
- Location (including longitude, latitude)

4) Earthquake record

- Earthquake name
- Station name
- Record ID
- Component (x, or y, or z direction)
- Hypo central
- Fault rupture
- Project rupture

- Site condition
- Data source
- Site classification USGS
- Site classification Geomatrix
- Filter points (Hz): HP, LP
- PGA, PGV, PGD
- Records

5) Other General Information about the Earthquake

- Information file
- Information source

2.3.3 Hazard Information: Flood/Scour

1) Bridge information related to flood/scour

- Bridge low chord elevation
- Bridge upper chord elevation
- Overtopping elevation
- Deck type
- Bearing type
- Parallel bridge yes/no
- Continuous abutment
- Vertical configuration
- Distance between center lines of a parallel bridge
- Distance between piers face of a parallel bridge

2) Bridge site related to flood/scour

- Stream name
- Waterway classification
- Flow skew angle
- Drainage area

- Slope in vicinity
- Stream size
- Flow impact bank
- Bed material
- Channel shape
- Guide bank

3) Pier information needed for flood/scour analysis

- Bridge station of the pier
- Pier alignment
- Pier type
- Pier width
- Pier shape
- Pier shape factor
- Pier length
- Pier protection
- Pier foundation
- Number of the piles
- Pile spacing center to center (of the column)
- Foot/pile cap width
- Top elevation
- Bottom elevation
- Cap shape
- Pile tip elevation

4) **Flood/scour information for the pier**

- Scour depth
- Accuracy
- Scour hole side slope
- Scour hole top width
- Approach flow velocity

- Approach flow depth
- Effective pier width
- Pier skew to flow
- Bed material type
- Bed form
- Water line on the pier
- Upstream or downstream (scour measurement)
- Debris

5) Abutment information needed for flood/scour analysis

- Skew to the flow
- Abutment/contracted open type
- Abutment slope
- Embankment slope
- Embankment skew to flow
- Length
- Wing wall
- Wing wall angle
- Bank length
- Abutment protection

6) Scour information for the Abutment

- Scour depth
- Flow velocity at abutment
- Scour depth at abutment
- Flow angle
- Bed material

2.3.4 Hazard Information: Vessel Collision

1) Bridge information related to navigation

- Number of piers
- Number of channel

- Navigation water depth
- Annual passing vessel number
- Navigation type
- Navigation curve
- Navigation width
- Navigation height
- Navigation divided
- Straight channel length in vicinity
- Pass difficulty under bridge

2) Channel information near bridge

- Channel name
- Channel path number
- Channel height
- Channel width
- Channel location
- Channel yaw angle
- Water level

3) Piers related with CV

- Pier location
- Pier type
- Pier/column shape
- Pier/column size
- Pier water depth
- Pier water lever
- Pier protection
- Pile type
- Pile cap shape
- Pile cap size
- Pile cap top elevation

4) Impact Information of the CV

- Impact position
- Impact angle
- Impact pier identity
- Pier protection
- Impact superstructure type
- Impact superstructure size
- Impact superstructure elevation
- Dent depth and width
- Other dent information

5) Passive collision avoidance of the pier

- PCA type
- PCA cost

6) Environment and weather

- Current angle
- Current velocity
- Average current velocity
- Wind angle
- Wind velocity
- Design wind velocity
- Visibility
- Day or night
- Design max. water lever
- Design min. water lever
- Average water lever
- Water season (water low or high month)
- Weather (sunny, rain, etc.)
- Floating ice

7) Vessel information

- Vessel name
- Vessel type
- Vessel material
- Vessel built year
- Vessel length
- Vessel width
- Vessel height
- Mast height
- Number of the vessel machines
- Propeller type
- Head propeller
- Traffic direction
- Velocity
- Owner
- Goods
- Passenger
- Power
- Empty tonnage
- Real tonnage
- Empty draft
- Real draft
- Flotilla line
- Flotilla column
- Flotilla barge

8) Barge

- Name
- Type
- Material
- Built year

- Length
- Width
- Height
- Empty tonnage
- Gross tonnage
- Load draft
- Real draft

2.3.5 Other Hazards

Truck Collision

1) Truck

- Truck type
- Truck driver
- Truck size
- Truck velocity
- Impact direction
- Gross weight
- Empty weight
- Truck mode
- Truck maker
- Made year
- Owner

2) Impacted Pier

- Pier type
- Pier shape
- Pier size
- Pile type
- Pile number

- Pile cap shape
- Pile cap size
- Impact position
- Impact angle
- Dent size
- Dent information

3) Impacted superstructure

- Impacted superstructure type
- Impacted superstructure size
- Impact position
- Impact angle
- Dent size
- Dent information

Fire

1) Fire information

- Fire location on the bridge
- Fire material
- Fire material weight
- Fire material calorific
- Fire release rate
- Fire temperature
- Fire time duration

2.3.6 Case Study Format

1) Case study

- Author
- Report

2) Case study document

- File name
- Information identification
- Information classification: event, site, bridge, vessel, CV, environment, highway, etc.
- Information content type
    - Event: general, injuries, vehicle, loss, other
    - Bridge: general, superstructure, column, bear, PCA, etc.
    - Site: general, flood, scour, environment, weather, stream, pier and abutment (about scour)
    - Vessel: general, vessel, etc.
    - Highway: general, etc.
    - CV: general, navigation, PCA, pier

SECTION 3
SUMMARY

A bridge can fail for many reasons, including internal causes (design error, material defect or aging, overloads, construction error, etc.) and external causes (extreme events such as earthquake, scour, flood, wind, vehicle or vessel collision, fire, etc.). Although there are several existing information sources such as the NYSDOT databases and other collected or summarized reports on bridge damage and failures, they are not sufficient to provide a fundamental basis for further improvement to the development of next generation of design specifications. In this study, the establishment of a comprehensive database of damaged bridges (DDB) is proposed, which integrates current existing bridge information sources with new information to provide a uniform database to catalog damaged bridges. The database includes the following topics: bridge design information (design documents, construction, drawings, etc.); environmental condition (geographical and weather); hazard information and traffic conditions; bridge damage and loss information (damage positions and damage modes, etc.); and economic and environmental impacts. This bridge damage database can also contribute to the ongoing long term bridge performance program of the FHWA.

The DDB can achieve the following objectives:

- Provide sufficient information for structural and statistical analysis of bridge damage/collapse
- Establishment and analyses of damaged bridge models
- Improvement of the AASHTO LRFD Extreme Event Design Limit State Equations and design principles
    - Enhanced load models
    - Calibrated the probability of failure or reliability of bridges
    - Target reliability determination
    - Identification of the importance of different resistances
- Statistical analysis and quantitative validation of MH-LRFD results with links to NBI and other databases as appropriate

- Better understanding and improved knowledge of MH bridge performance
- Improved life-cycle cost analysis for MH
- Improved highway bridge systems model in HAZUS-MH (FEMA 1997) (damage state calculation model, direct economic loss model, etc.)

The DDB framework is established to allow continuous development. For example, information about the bridge condition at the time of failure is essential for understanding the failure modes and causes of the bridge failure. These conditions may be determined from historical data about regular maintenance, retrofitting, repair, and reconstruction, as well as from inspection reports. In the future, Figure 1-5 will be modified as shown in Figure 3-1.

Cooperation with experts from various fields can significantly improve the accuracy and efficiency of the DDB, as shown in Figure 3-1. For example, it is necessary to work with geologists to further improve the current hazard models. It is also important to cooperate with economists to obtain a more reasonable understanding of the impact of direct and indirect losses in each bridge failure. In addition, the entire process for determination of LRFD design limit state equations must also include in-depth and comprehensive professional experience and judgment.

Several national or international workshops will be needed to (1) establish standard measures for different hazards and bridge conditions, (2) develop a commonly understood and accepted format for better communications, and (3) discuss the effort involved with data mining of past bridge failures. The continuous development and content additions to the DDB can provide a solid foundation to update design specifications, especially those that can contribute to a comprehensive reliability-based design method – MH-LRFD.

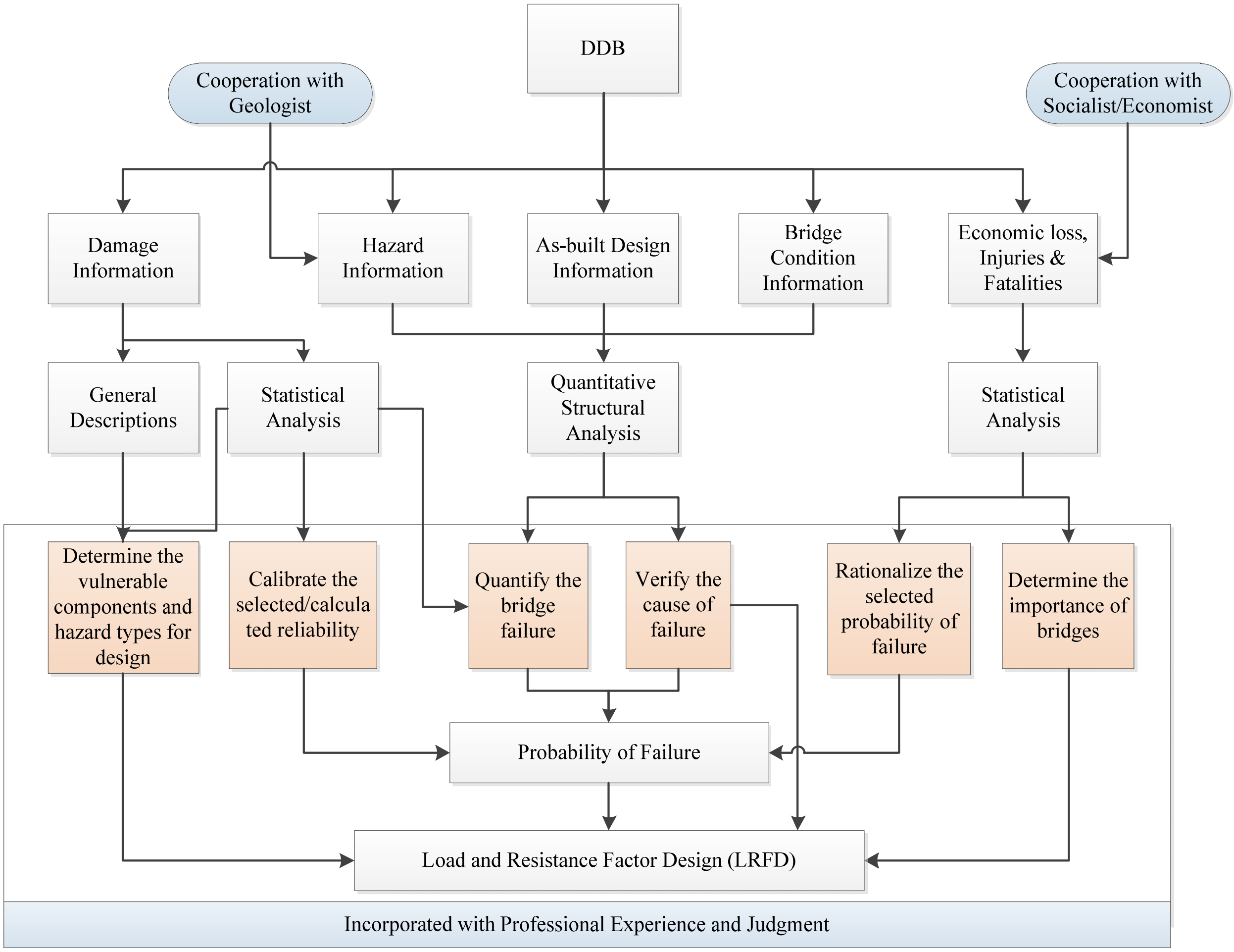

Figure 3-1 Improved Organization of the DDB

SECTION 4
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APPENDIX A:
DDB USER MANUAL

The fundamental and kernel components of the DDB are three Access database files, HWNBI_BRIDGE, NYSDOT_BRIDGE_FAILURE, and FAILED_BBRIDGE, which are described as follows:

- HWNBI_BRIDGE: This access database file was transferred from FHWA test files (NBI 2007), and was updated to the current version. There is some missing information in some of the bridge files.
- NYSDOT_BRIDGE_FAILURE: Access database file from NYSDOT (2006).
- FAILED_BBRIDGE: More data for damaged bridges needs to be collected. It is very difficult and time-consuming to search and collect the data resources as well as to input and analyze the collected data. Only several damaged bridges were collected herein for demonstration purposes (one damaged by flood/scour, one damaged by vessel collision and some bridges damaged by earthquakes).

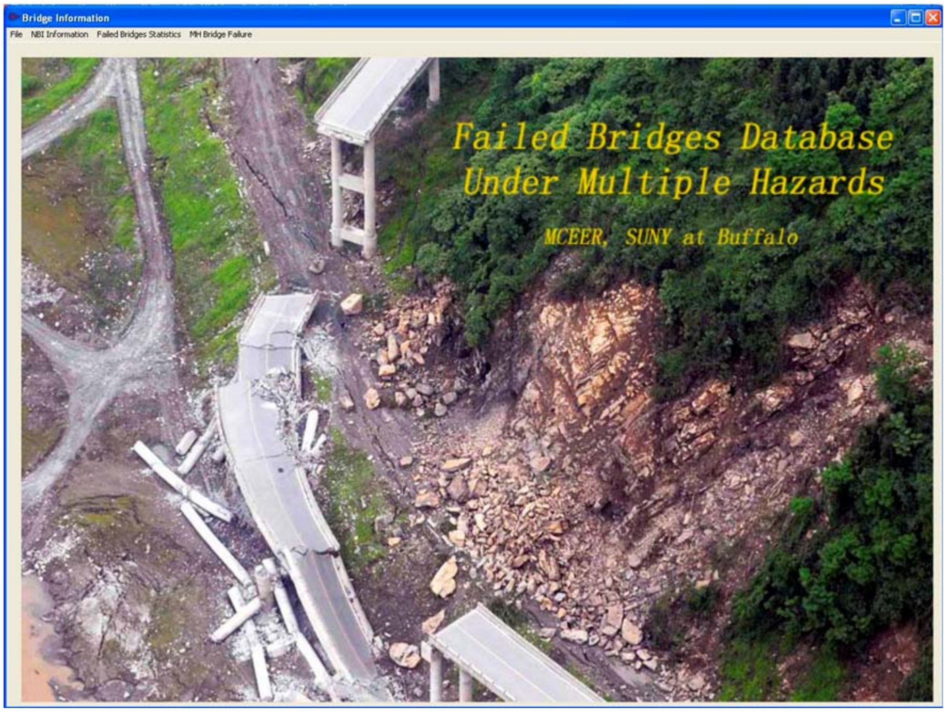
The DDB includes many graphic and document files, which are saved in different directories. These files must be included in the software and copied using the correct paths.

The interface program itself is not very difficult to code, but designing a user-friendly, convenient and rapid search interface is not an easy task. Suggestions from users will be important to continuously improve and perfect the code. This version of the program is provided for demonstration use and needs to be improved and revised in the future.

A.1 User Interface

The general menu (main menu) includes three items:

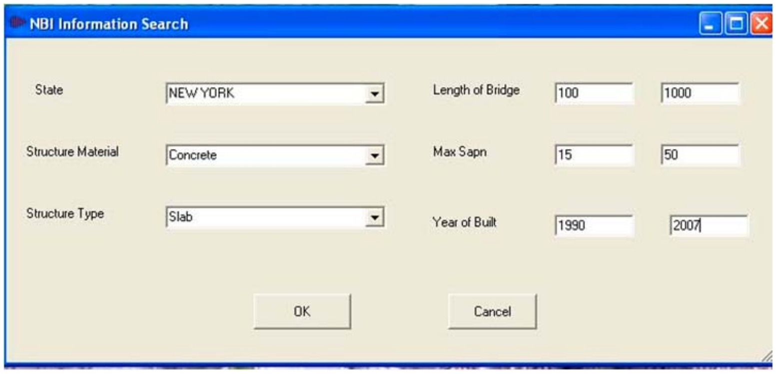
- NBI information
- Failed bridges statistics
- MH bridge failure



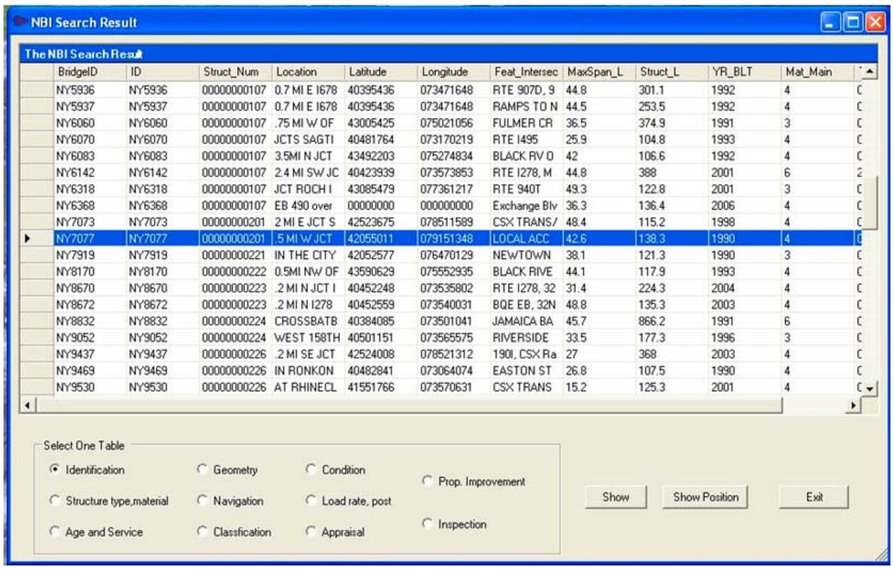
A.1.1 NBI Information Interface

There are four submenus under NBI information: 1) general search; 2) structure number search; 3) position search; and 4) statistics.

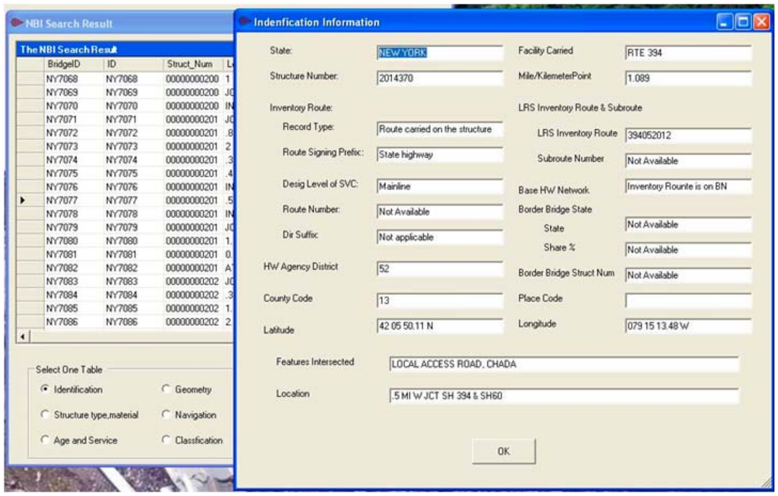
1) General Search



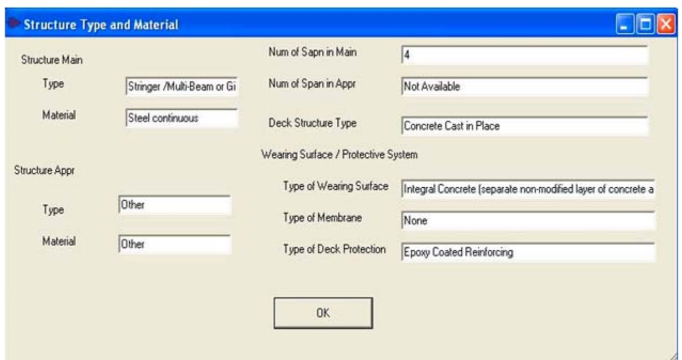
a) Set the search conditions; the interface for general search results will be shown



b) Look for the bridge and select the information needed. Then, the following window will provide details about the selection.

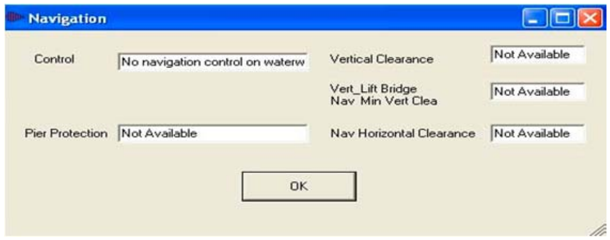


c) Structure and Material interface

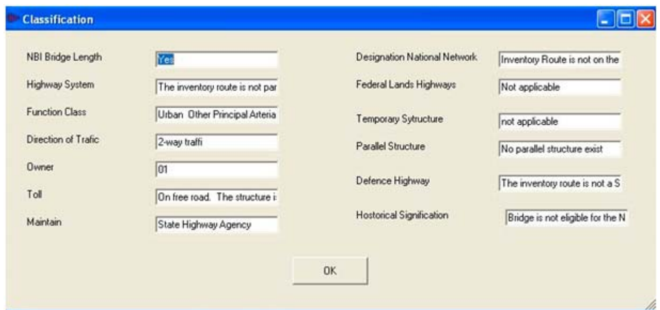


d) Age and Service interface

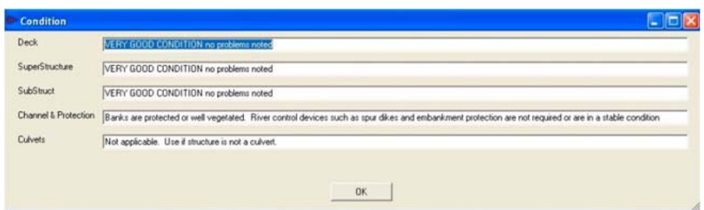
e) Navigation interface



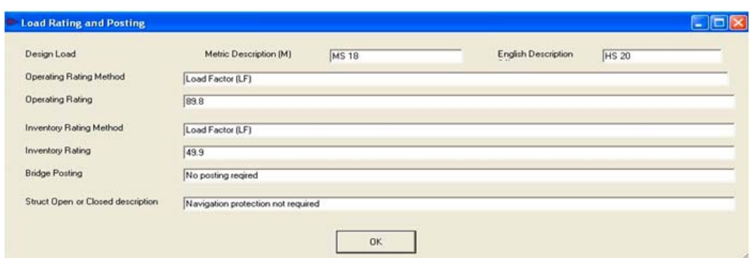
f) Classification interface



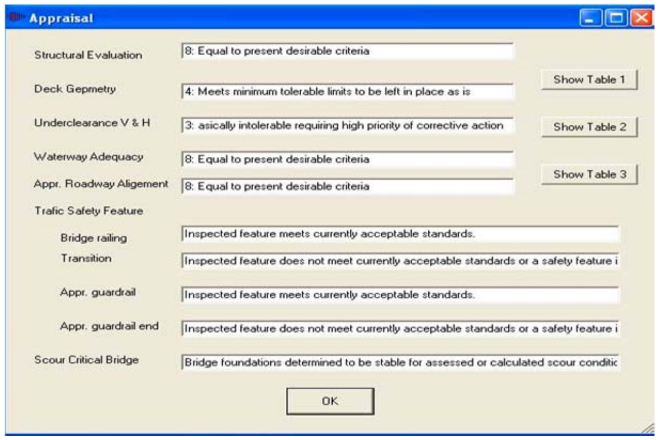
g) Condition interface



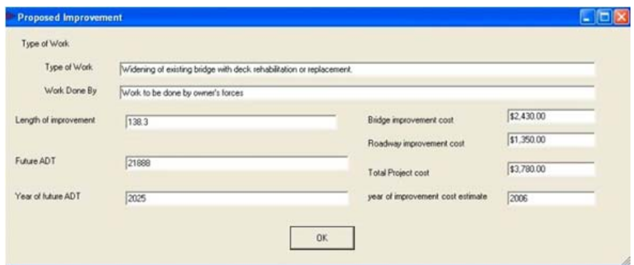
h) Loading rating and posting interface



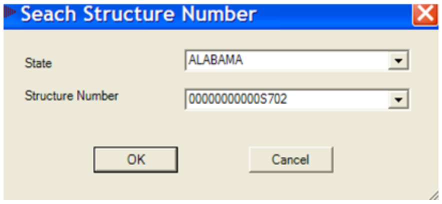
i) Appraisal interface



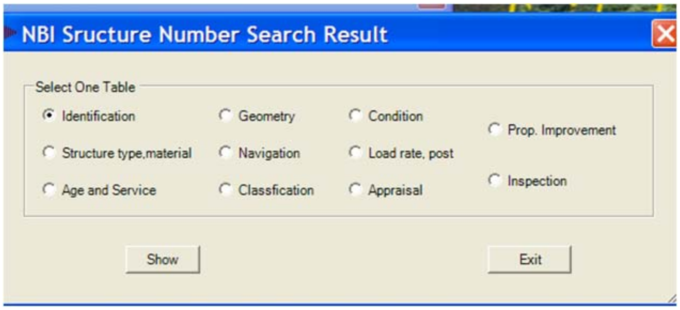
j) Proposed improvement interface



2) Structure number search interface



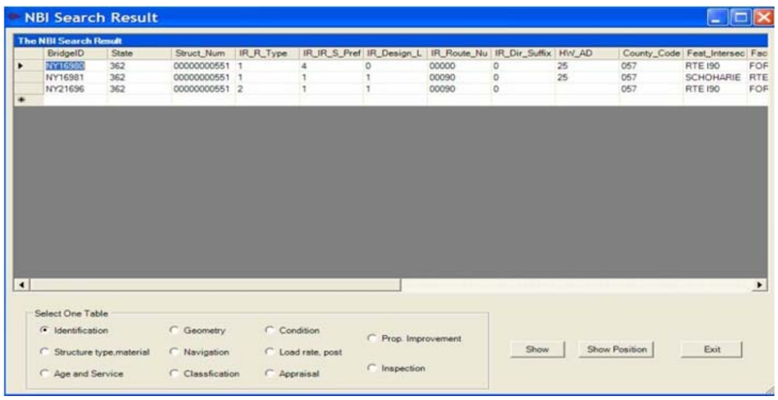
a) Select state and structure number; the search results interface will be displayed.



b) Then, select the property group of interest. The result will be shown the same way as in the general search.

3) Position search interface:

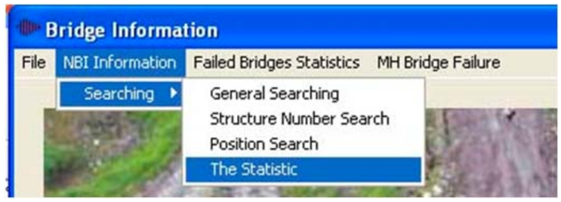
a) The latitude uses the format "xxxxxxxx," which means xx° xx" xx.xx'. The longitude uses the format "xxxxxxxxxx," which means xxx° xx" xx.xx'. The search interface is as follows:

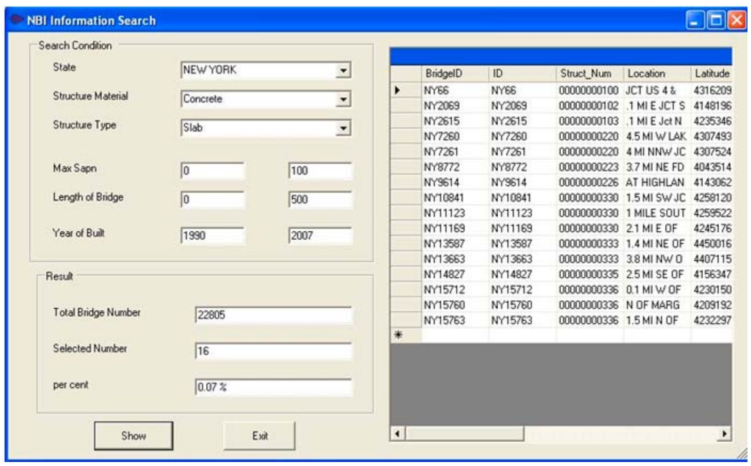


b) Then, select the bridge and the property. The results will be shown in the same way as in the general search.

4) Statistics

This is a very simple statistics search. Select the state and other conditions of interest. Then, the percentage of this type of bridge in the total number of existing bridges in the selected state will be shown.

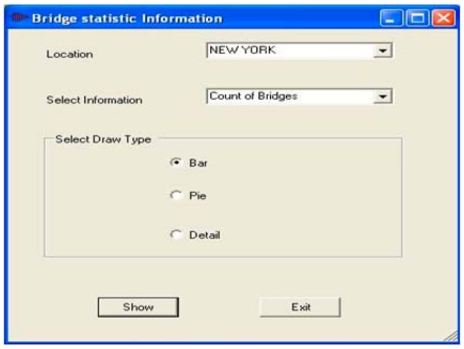




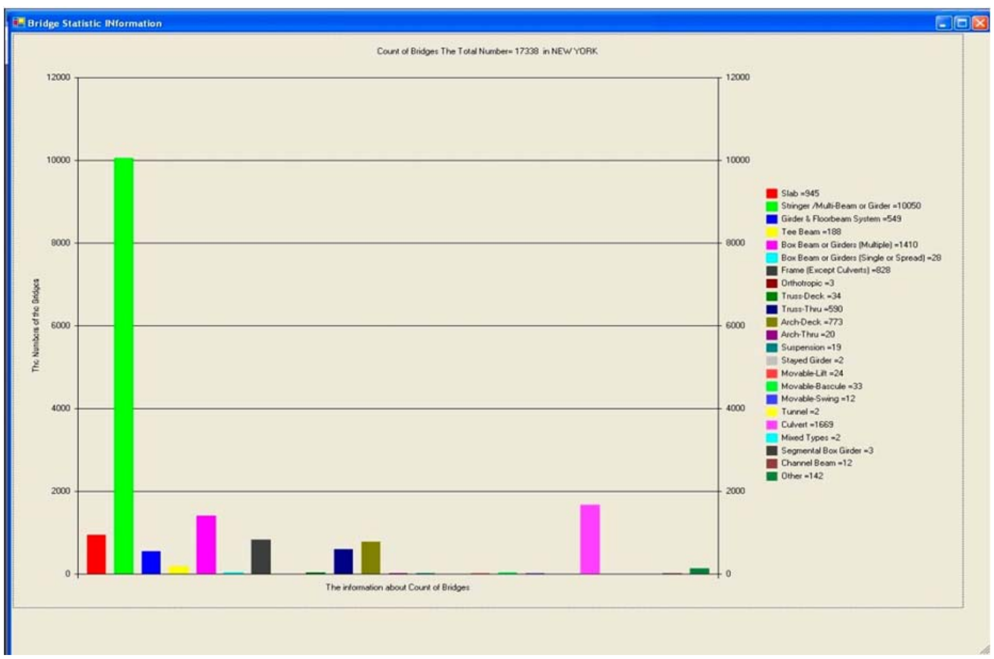
A.1.2 Statistics about Bridges that Failed

This search for statistics about failed bridges is based on the NYSDOT database. The following types of information are provided: (1) bridge statistics; (2) bridge failure; and (3) bridges that failed due to a given condition.

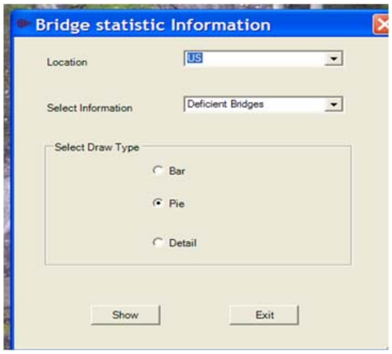
1) Bridge statistics

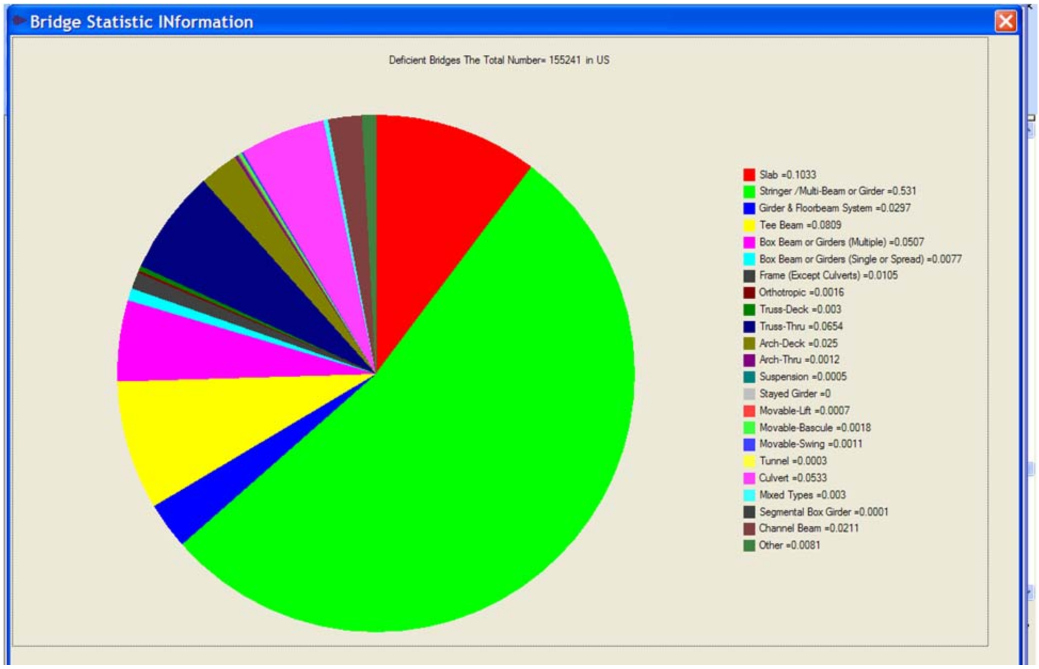


- Bridge count information

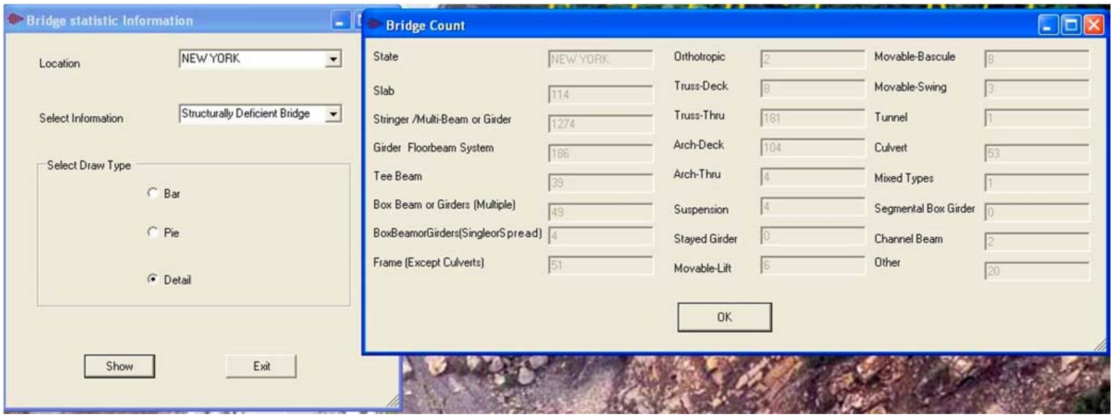


- Deficient Bridge information

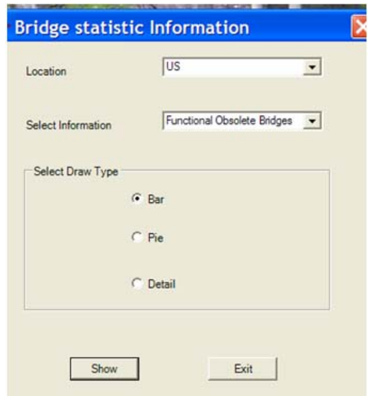


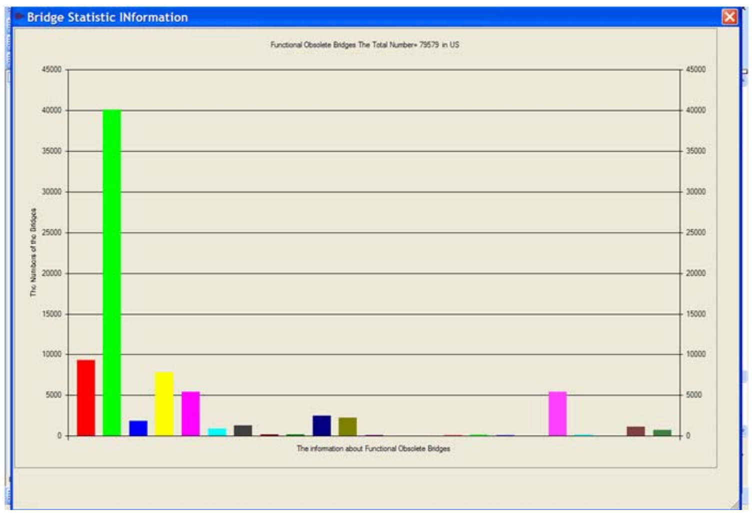


- The details about structurally deficient bridges are shown below.



- A bar chart for Functional obsolete bridges is shown below:

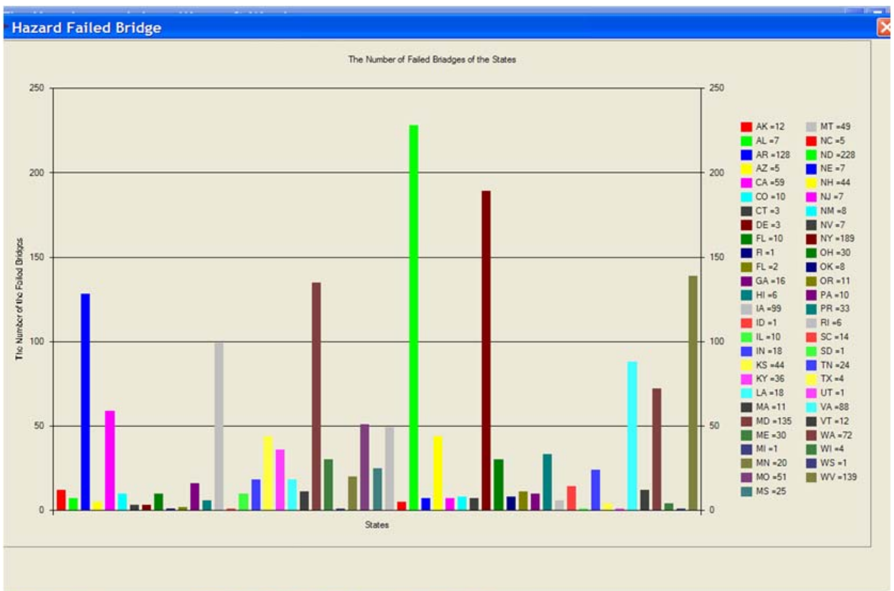




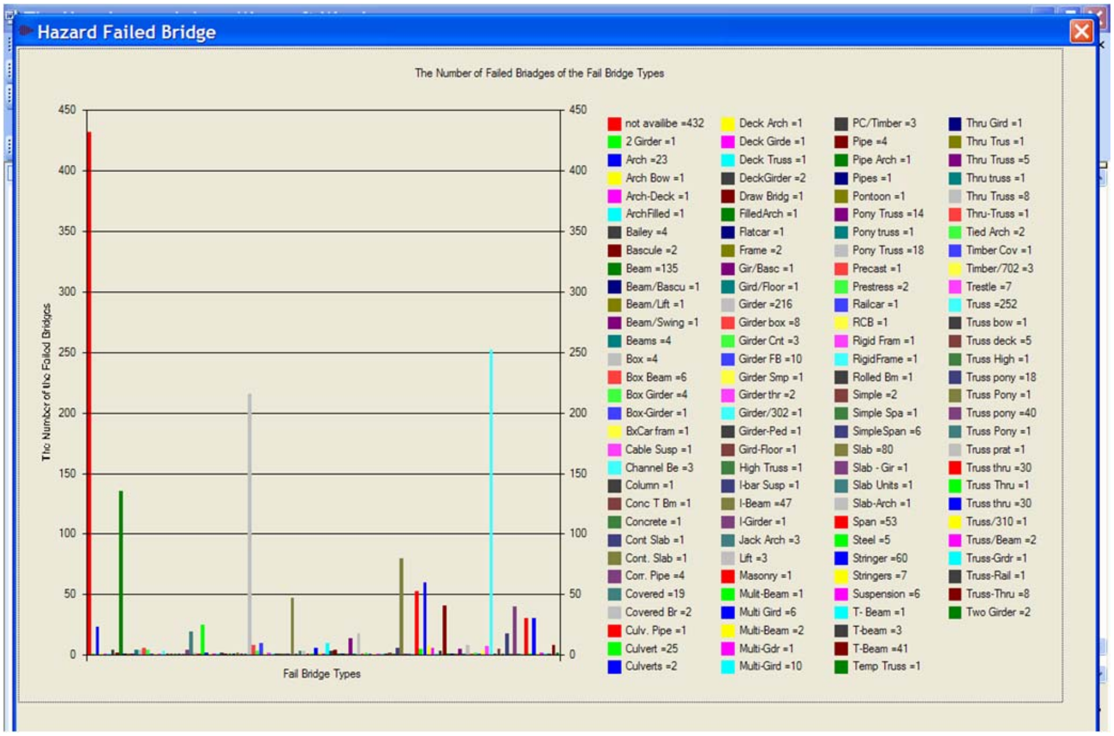
2) Bridge failure information

- Select the search conditions:

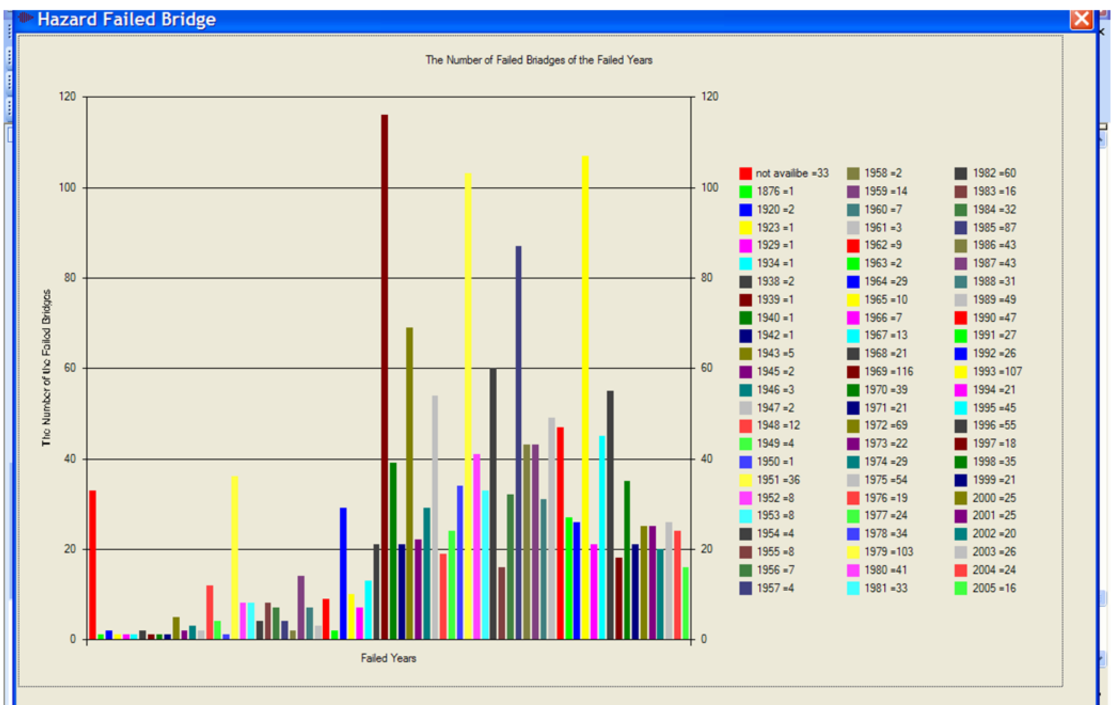
- Number of failed bridges in different states



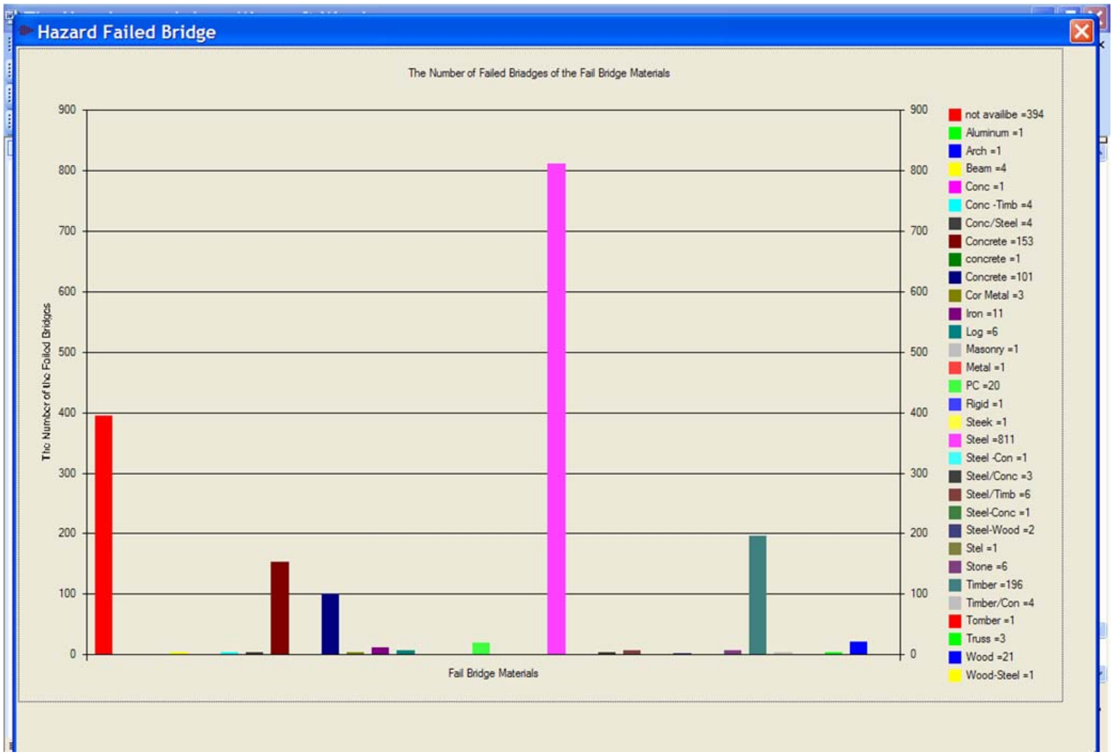
- Failed bridges for different bridge types



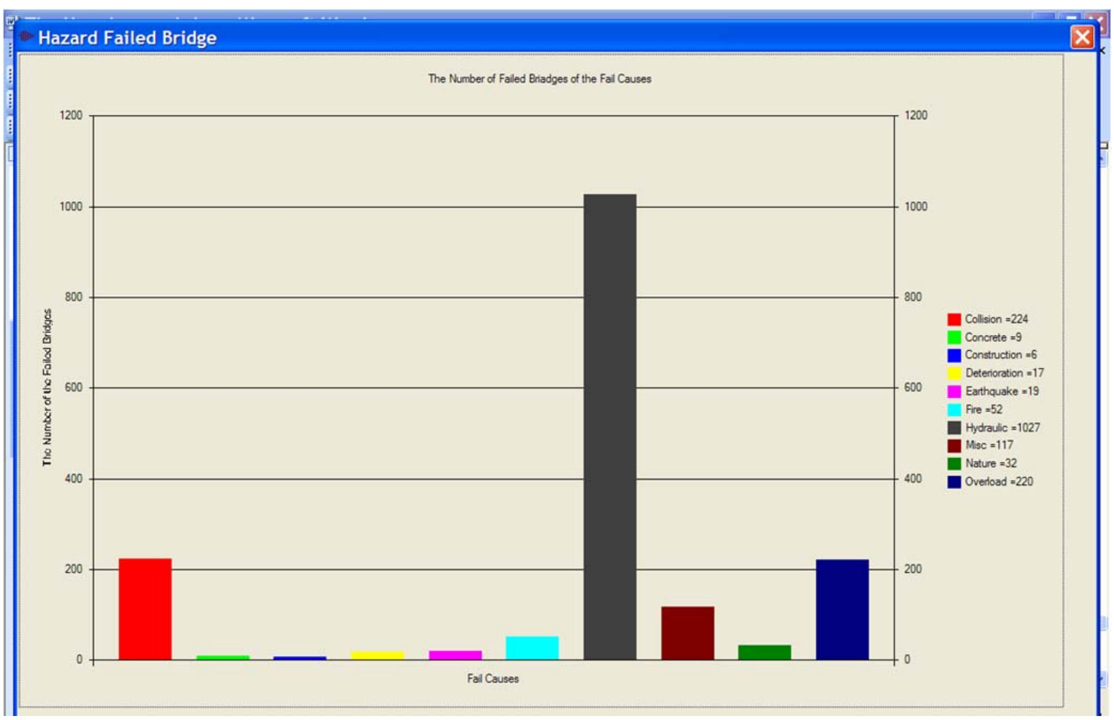
- Failed bridges in different years



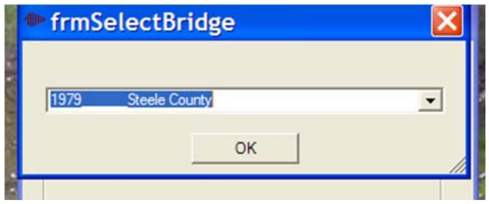
- Failed bridges of different materials

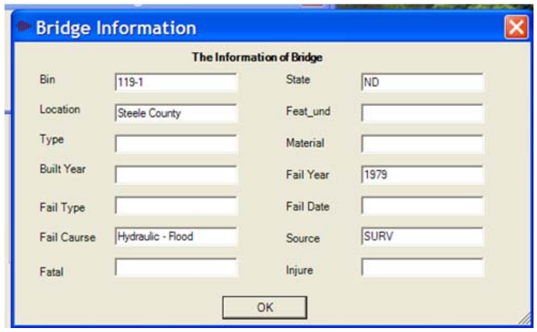


- Different causes of bridge failure.

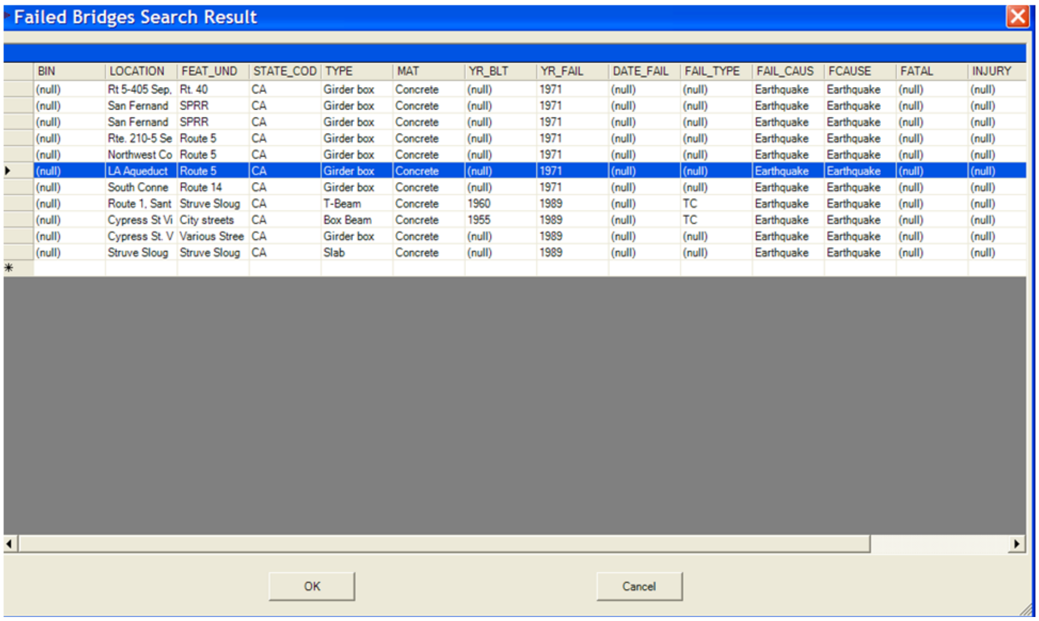


Select the detailed failure information for a selected bridge

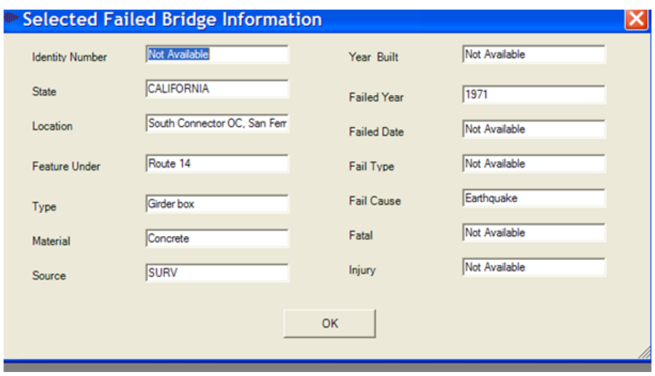




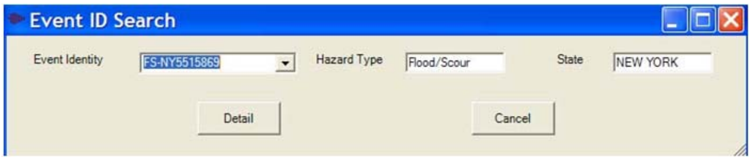
3) Search failed bridges according to a specific condition

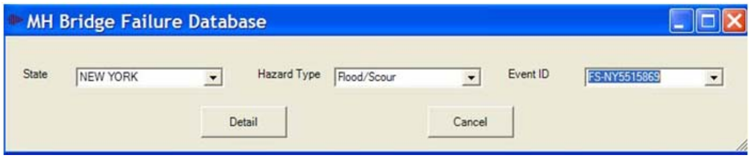


BIN	LOCATION	FEAT_UND	STATE_COD	TYPE	MAT	YR_BLT	YR_FAIL	DATE_FAIL	FAIL_TYPE	FAIL_CAUS	FCAUSE	FATAL	INJURY
(null)	Rt 5-405 Sep.	Rt. 40	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	San Fernand	SPRR	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	San Fernand	SPRR	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	Rte. 210-5 Se	Route 5	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	Northwest Co	Route 5	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	LA Aqueduct	Route 5	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	South Conne	Route 14	CA	Girder box	Concrete	(null)	1971	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	Route 1, Sant	Struve Sloug	CA	T-Beam	Concrete	1960	1989	(null)	TC	Earthquake	Earthquake	(null)	(null)
(null)	Cypress St Vi	City streets	CA	Box Beam	Concrete	1955	1989	(null)	TC	Earthquake	Earthquake	(null)	(null)
(null)	Cypress St. V	Various Stree	CA	Girder box	Concrete	(null)	1989	(null)	(null)	Earthquake	Earthquake	(null)	(null)
(null)	Struve Sloug	Struve Sloug	CA	Slab	Concrete	(null)	1989	(null)	(null)	Earthquake	Earthquake	(null)	(null)



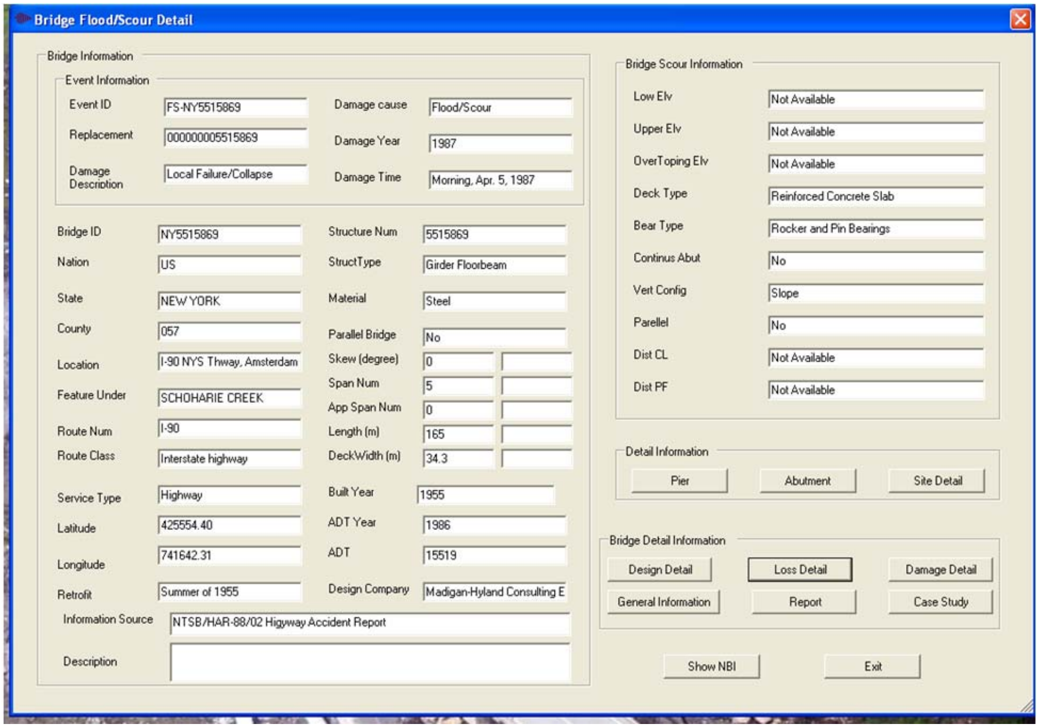
A.1.3 MH Bridge Failure Interface





Information for bridges damaged due to multi-hazards can be search by state and hazard type or the event identification as described above. Three examples are included in the database and are as follows: (1) flood/scour; (2) earthquake; and (3) vessel collision.

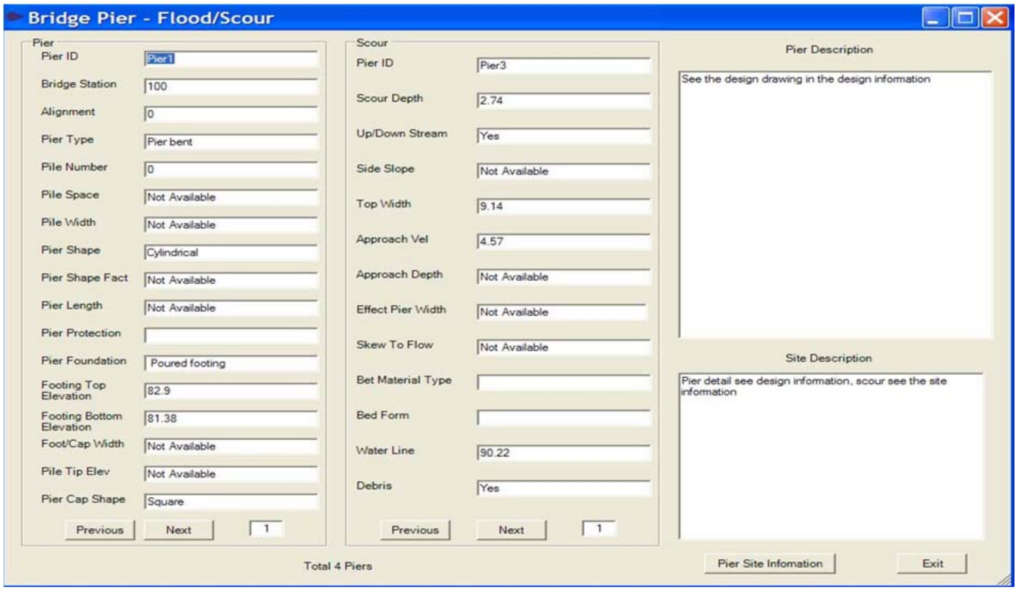
1) Flood/Scour interface



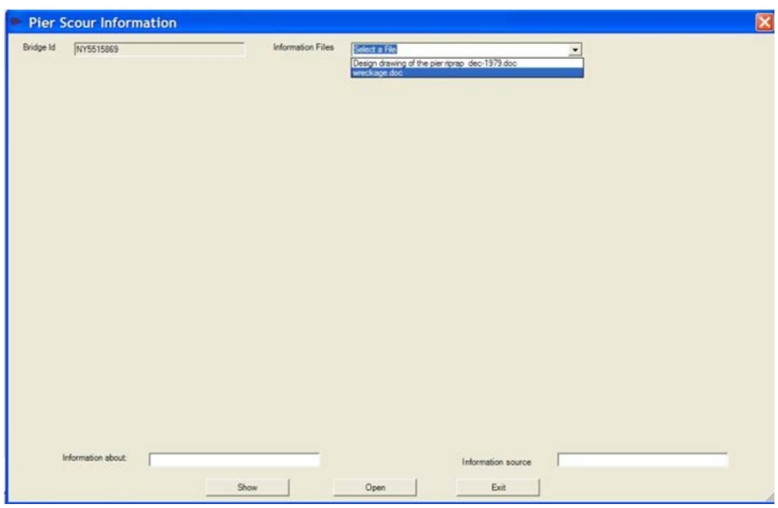
This part includes the event, basic information about the bridge and bridge scour information. There is some common information for all hazards such as bridge detail information, which includes design, damage, loss, general, case study and report. It can incorporate information about the bridge from the NBI database, if the bridge is included in it. Or, it can be used to replace or update the bridge information in NBI database. It also includes scour information about the pier, abutment and site.

a) The following shows the scour detail information about the pier, abutment and site.

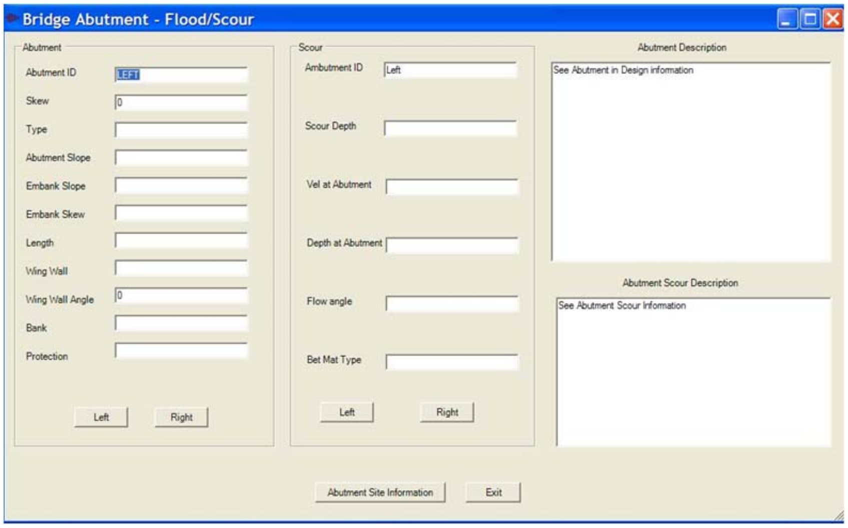
- Pier and scour information interface



- Pier site information interface (from pier and scour information)

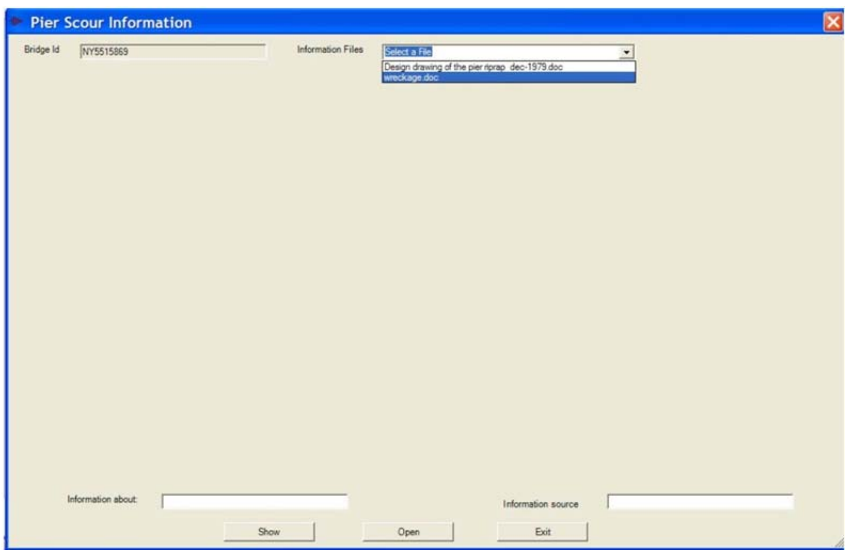


• Abutment and scour information interface



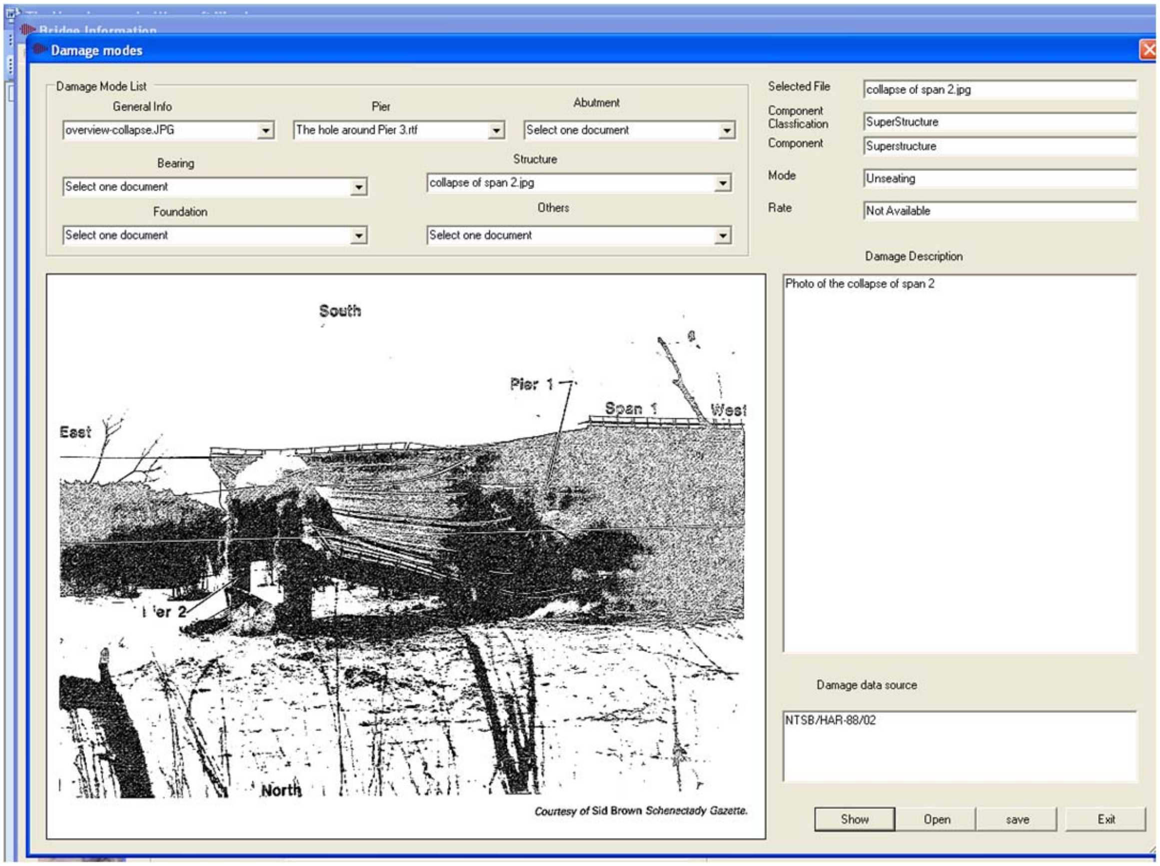
It also can obtain the abutment site information (from abutment).

• Site scour information

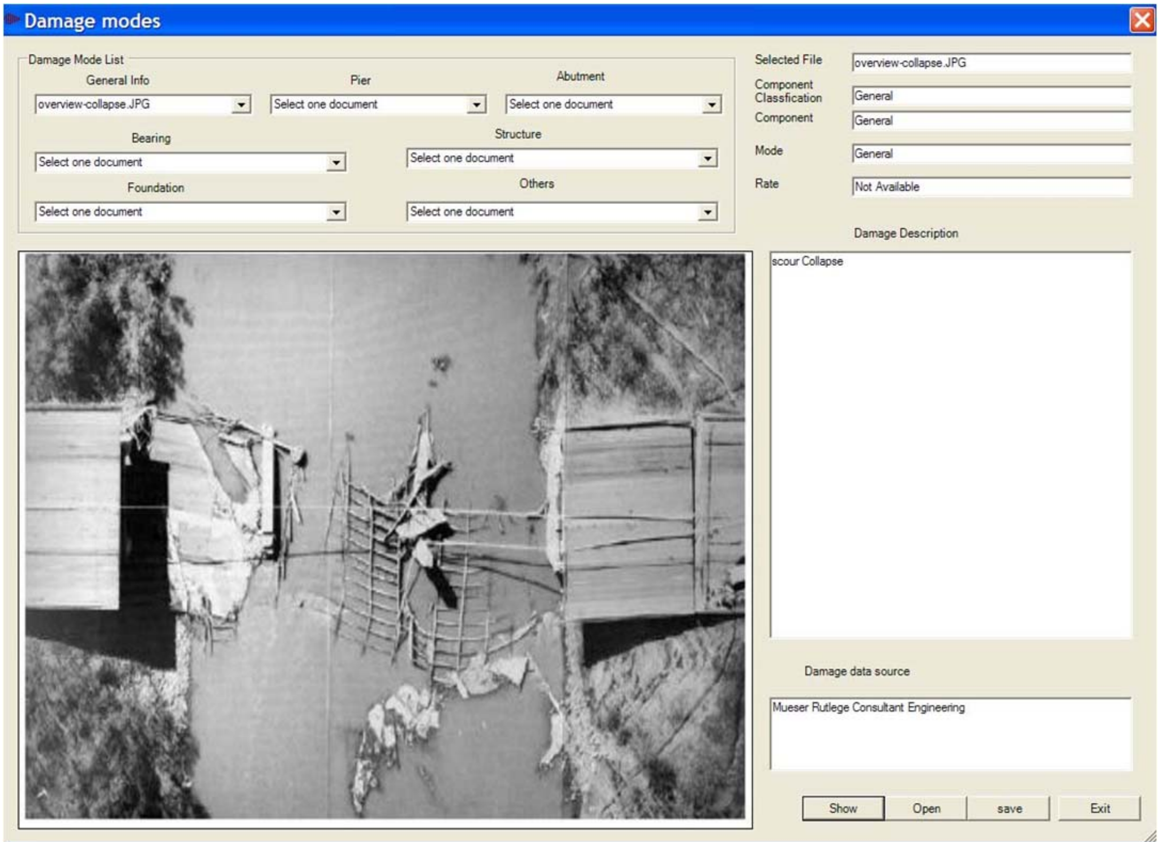


b) Detailed information about the bridge

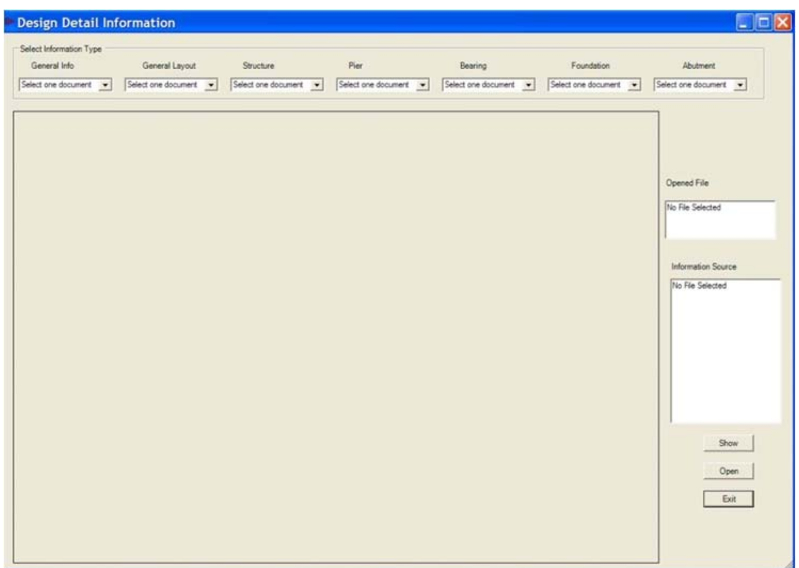
- Damage information interface
- Damage mode information interface



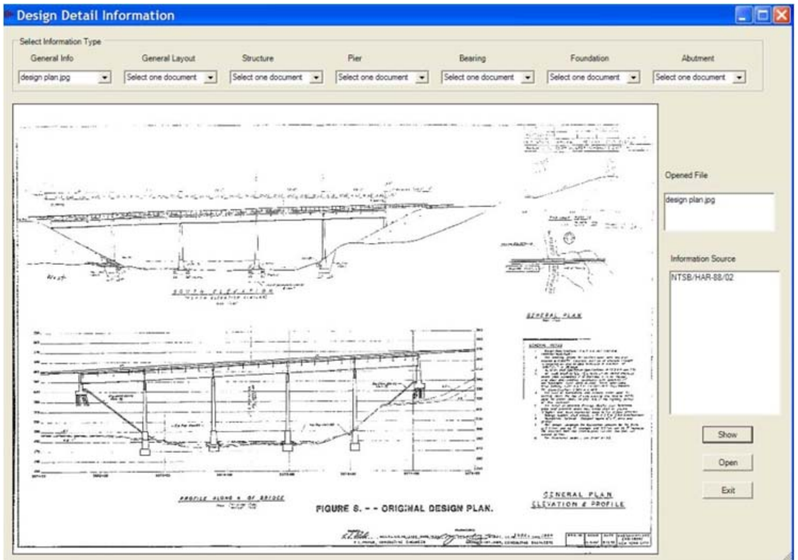
- Damage mode information interface

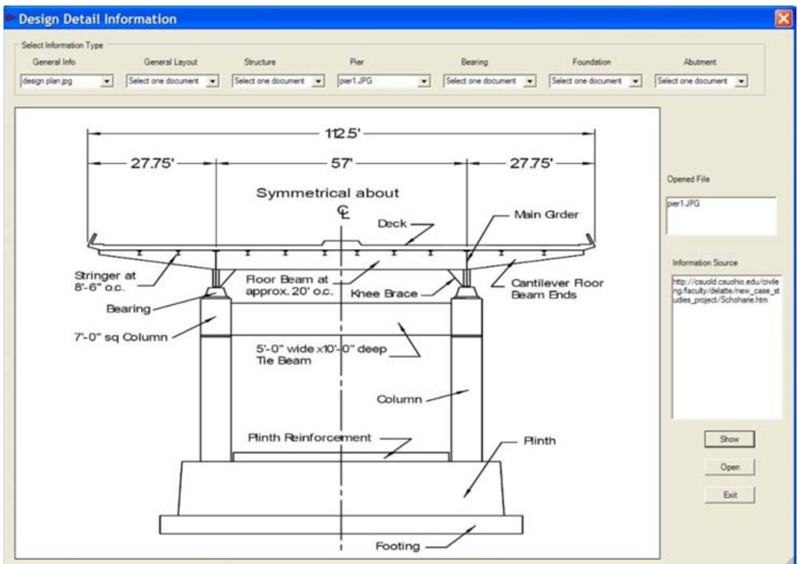


- Design information interface

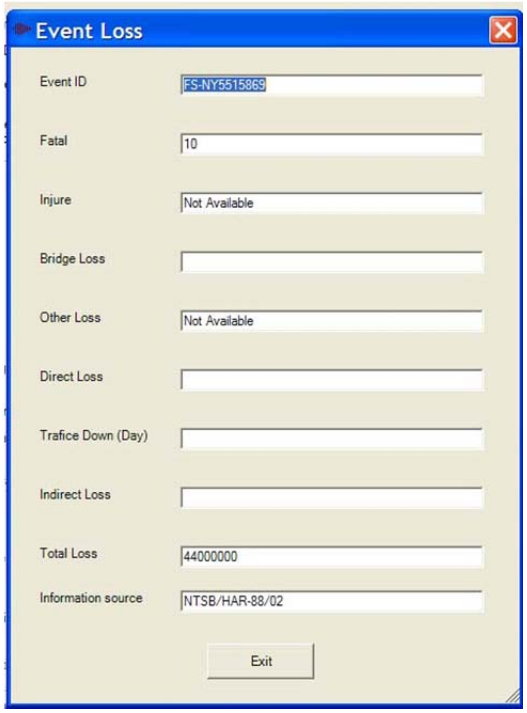


• Detailed design information interface

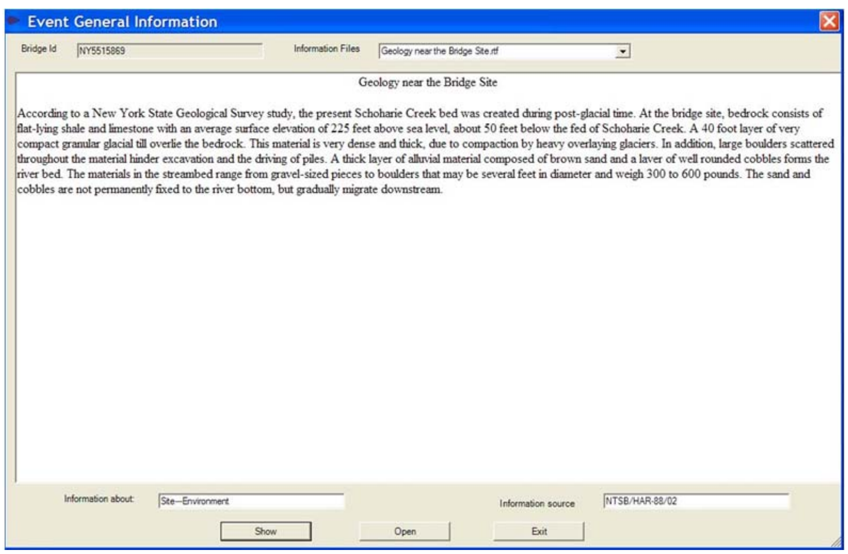




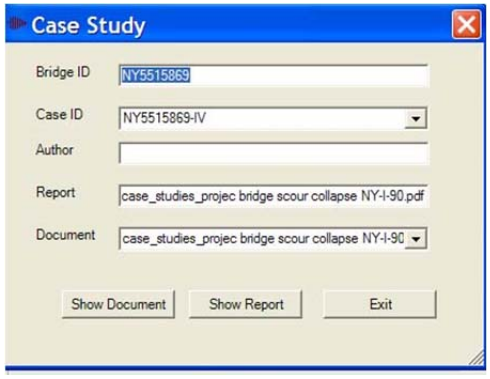
- Loss information interface for a given event



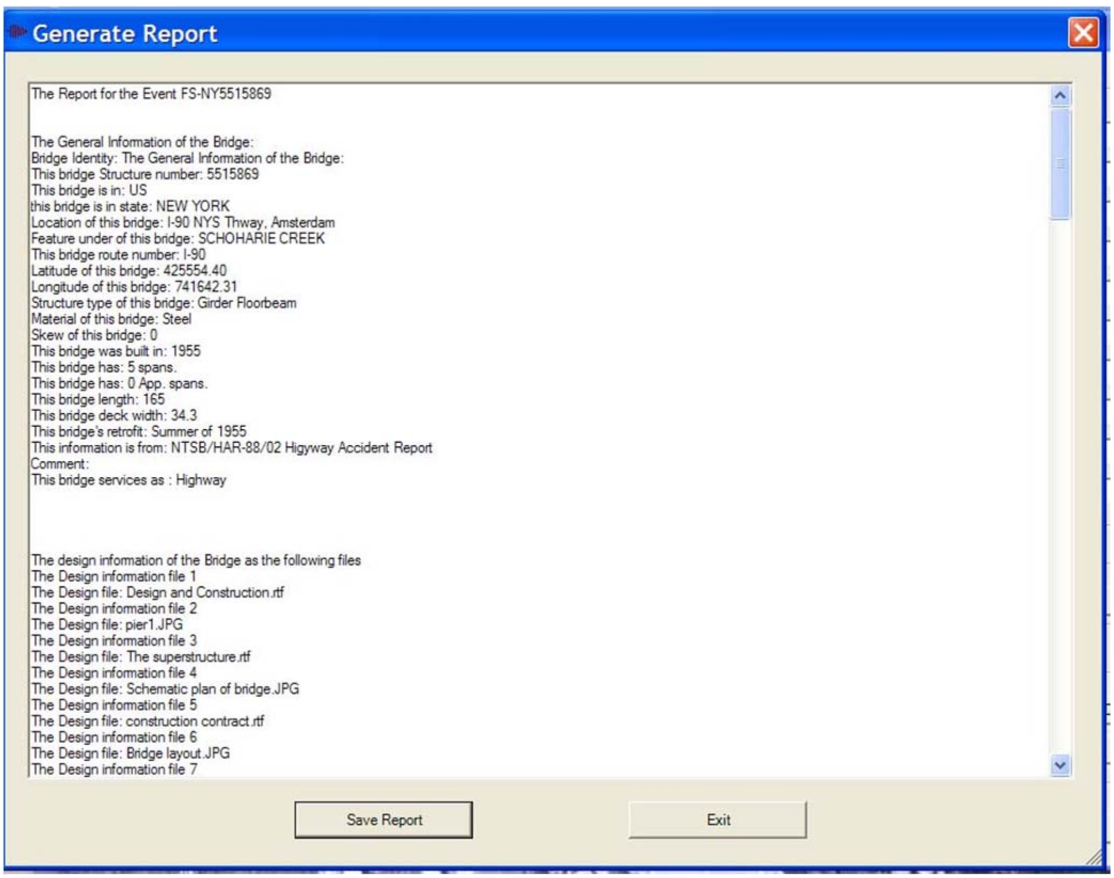
- General information about the bridge



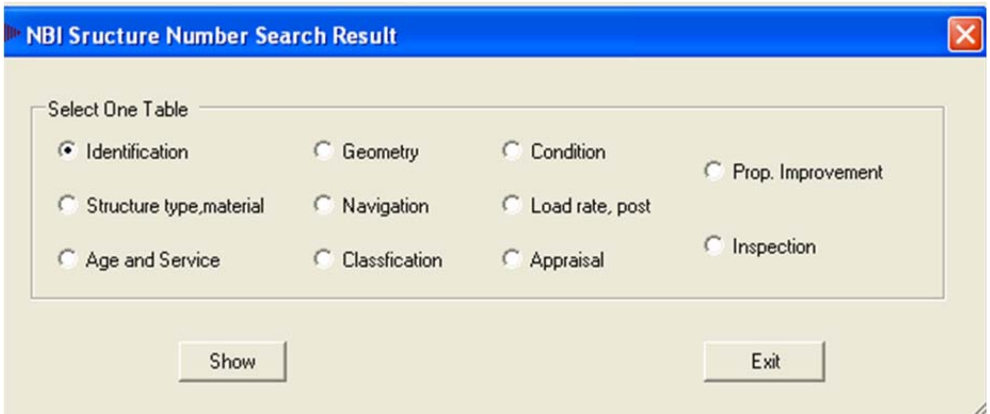
- Case study interface



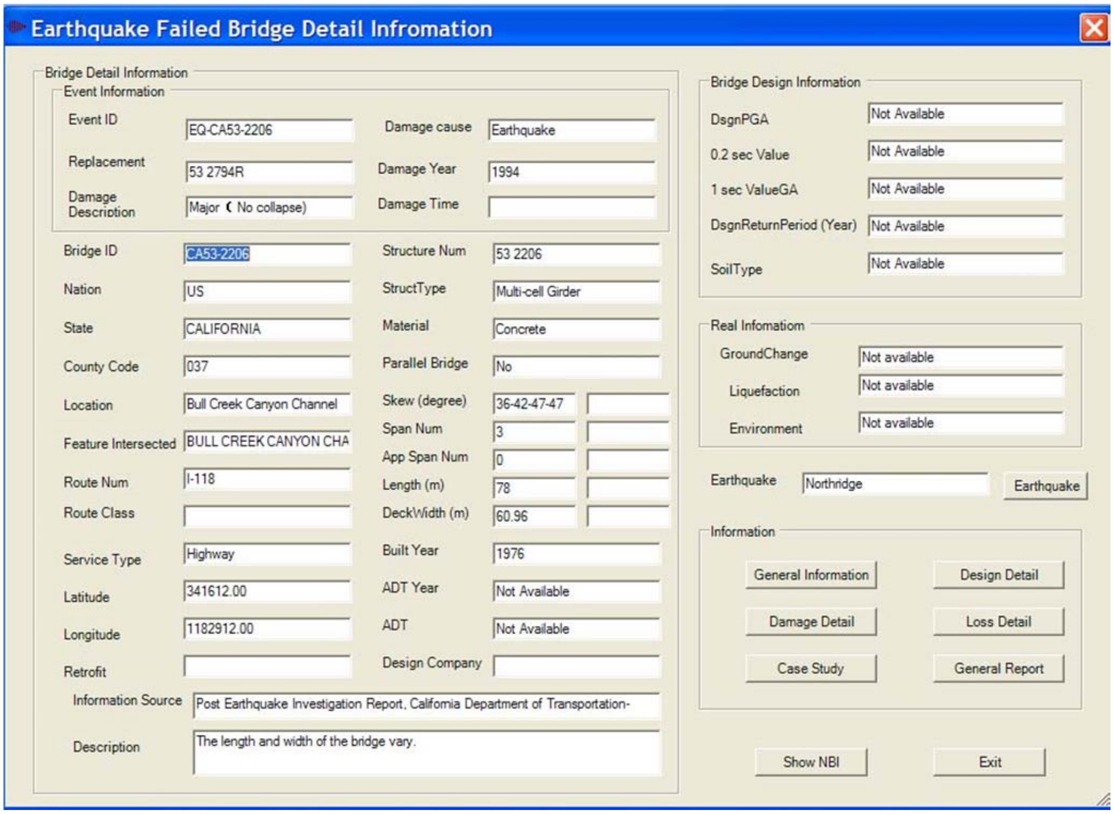
- Report interface



- NBI information interface

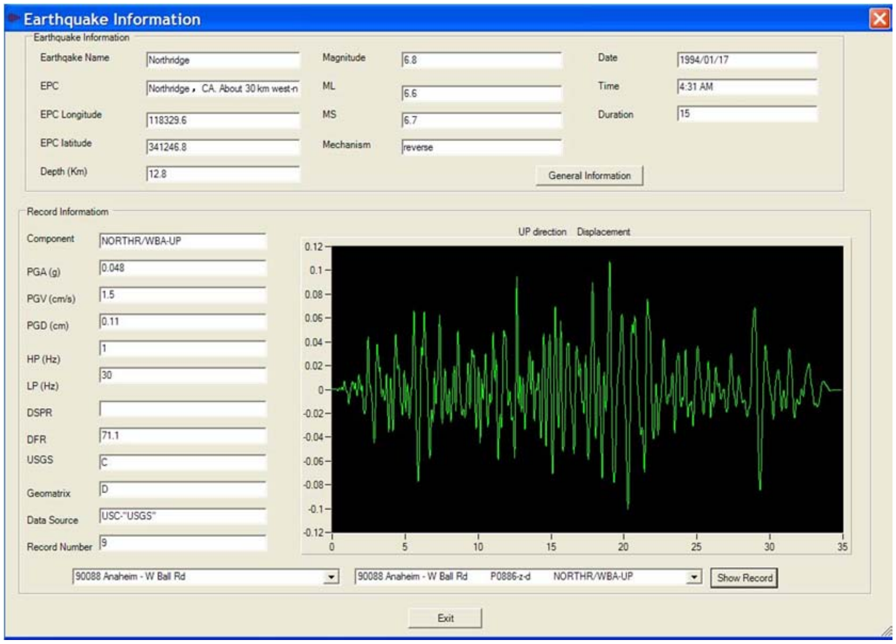


2) Earthquake information



This part includes the event, basic information about the bridge and earthquake information. Similar to the flood/scour hazard, there is common information for all hazards and bridge detail information. This includes design, damage, loss, general, case study, and report.

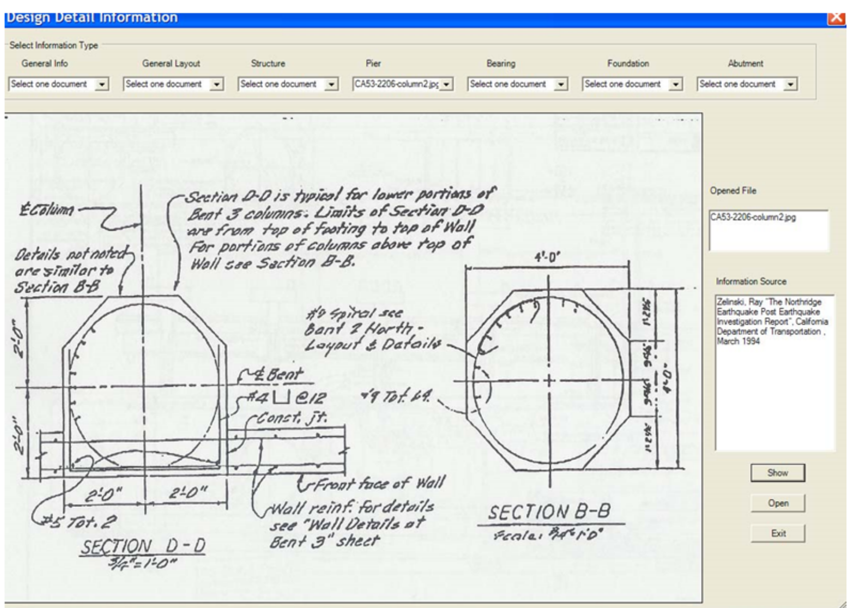
a) Earthquake information interface

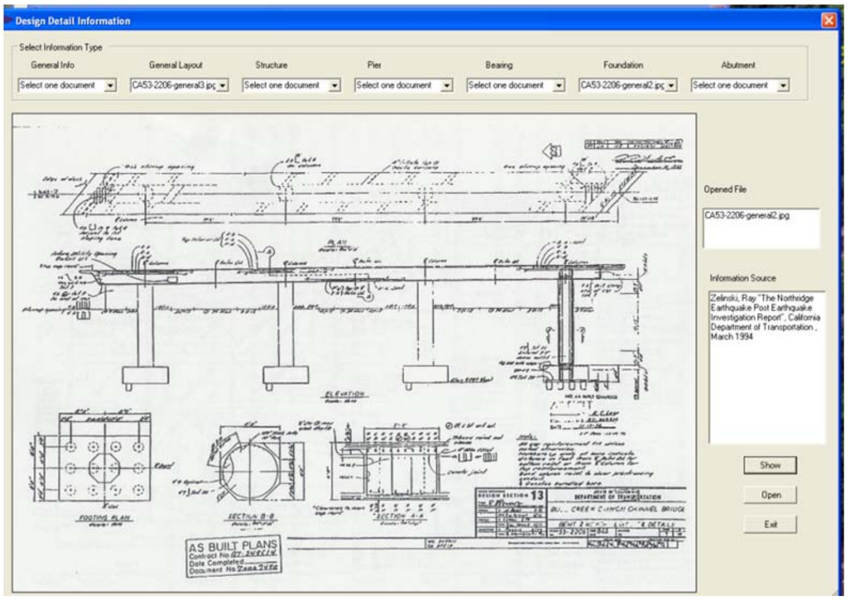


b) Bridge detail information

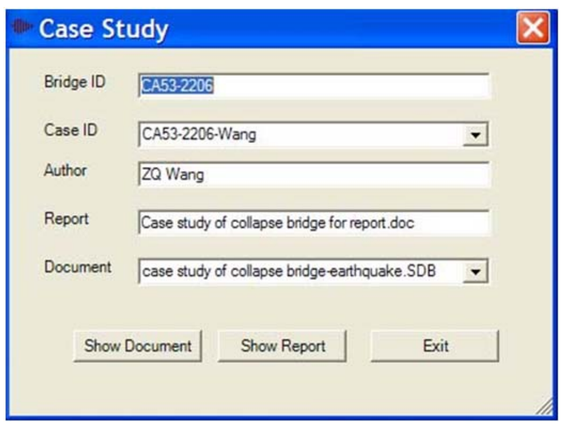
Similar information is included in the earthquake section as in the flood/scour section.

- Design information

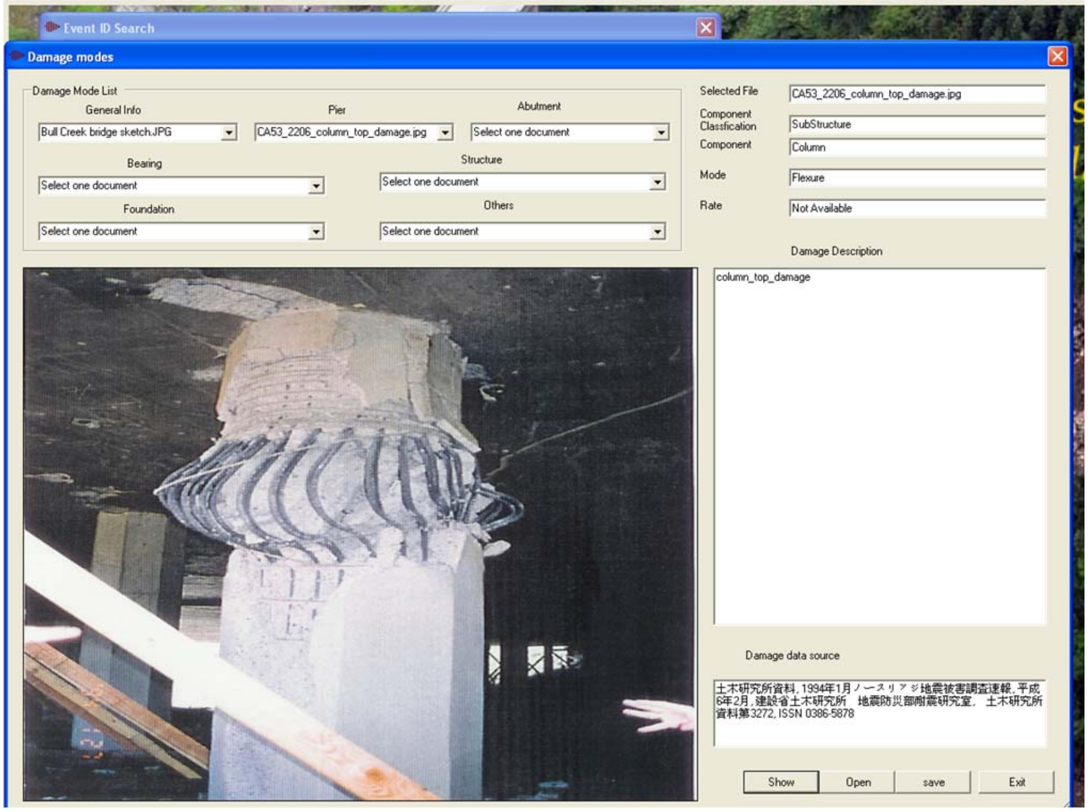


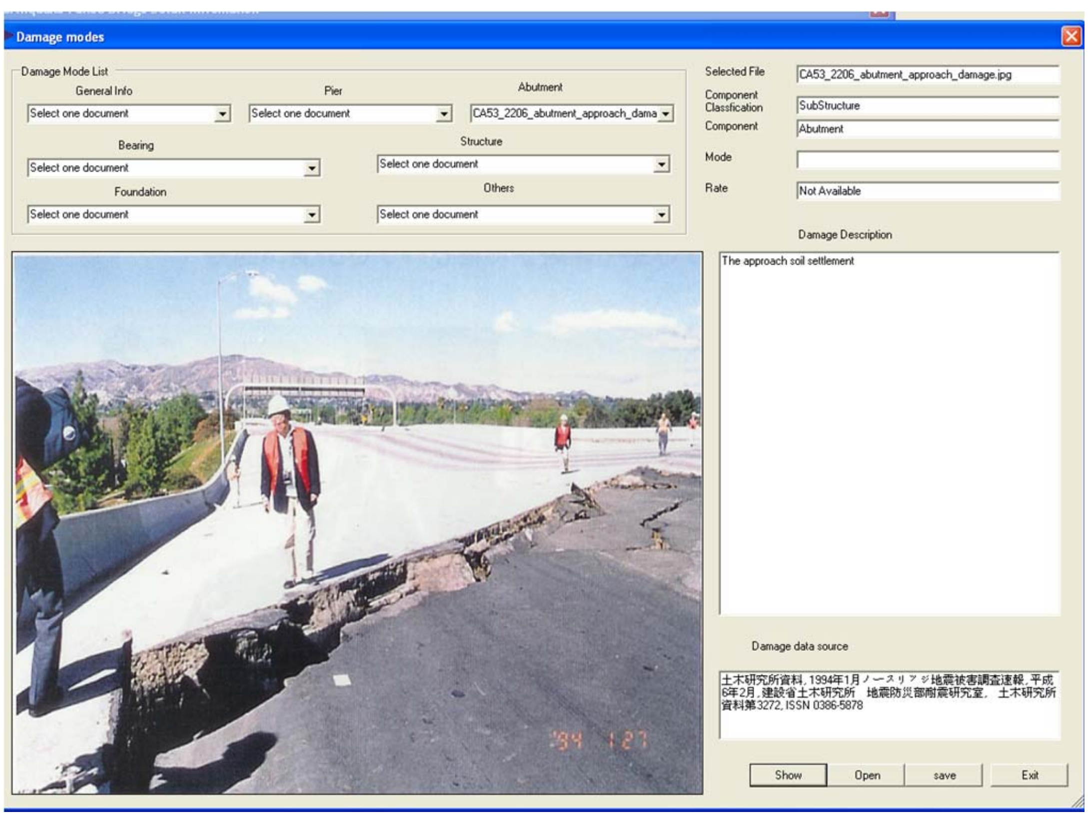


• Case study information interface

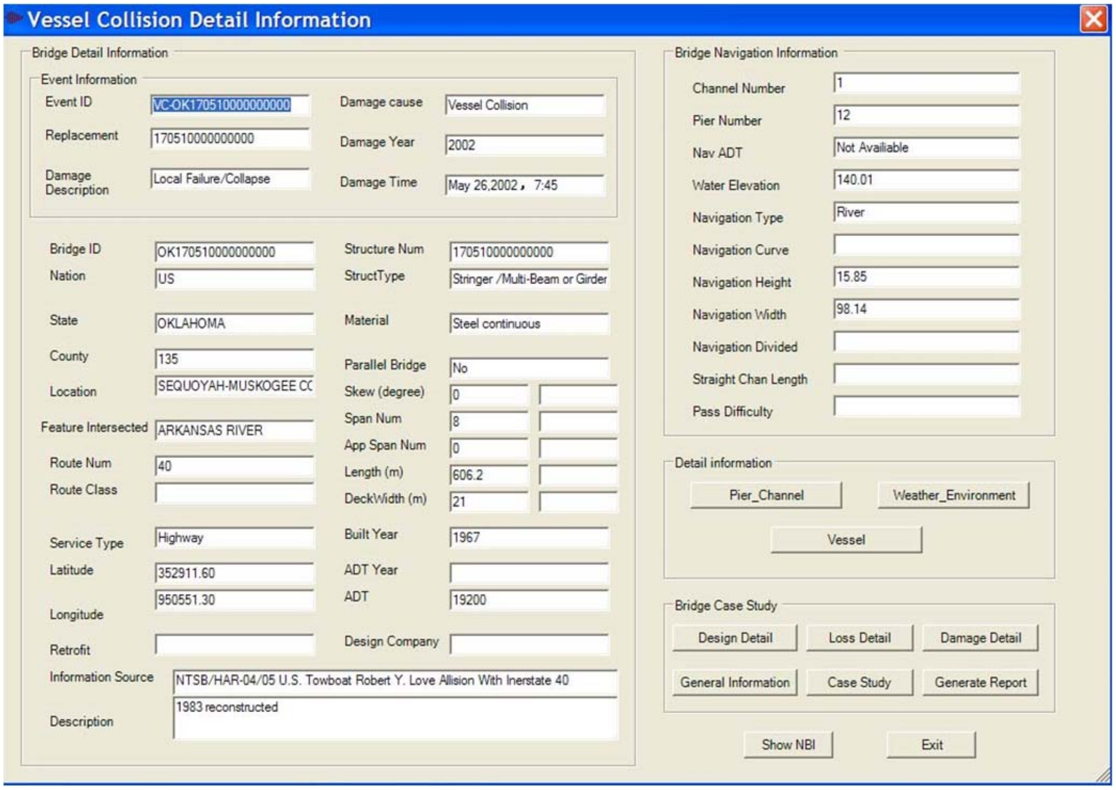


- Damage information interface





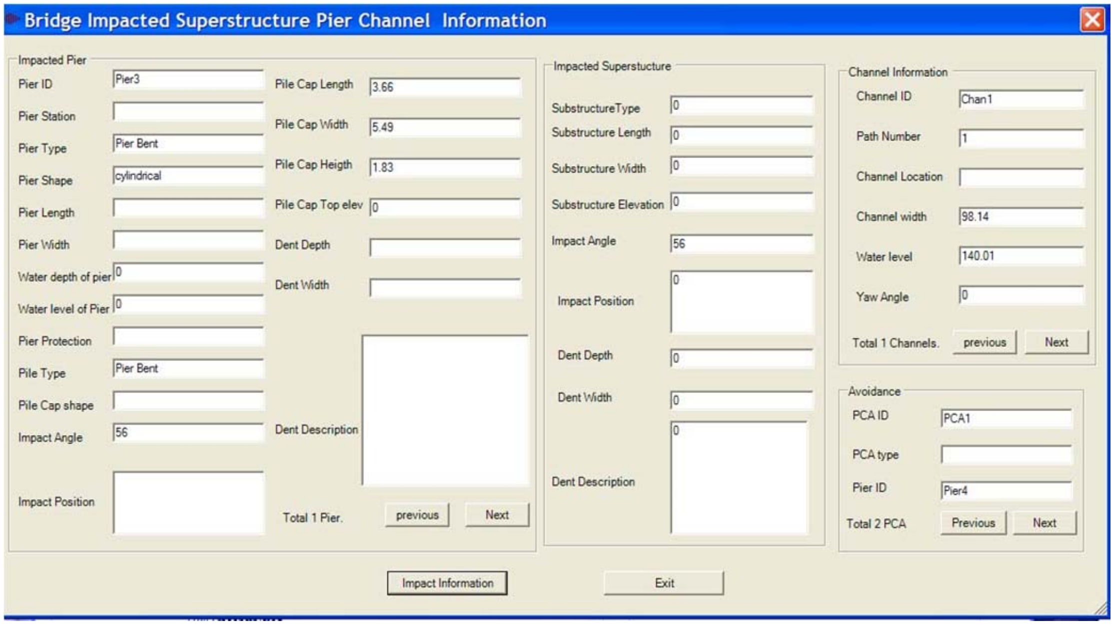
3) Vessel collision



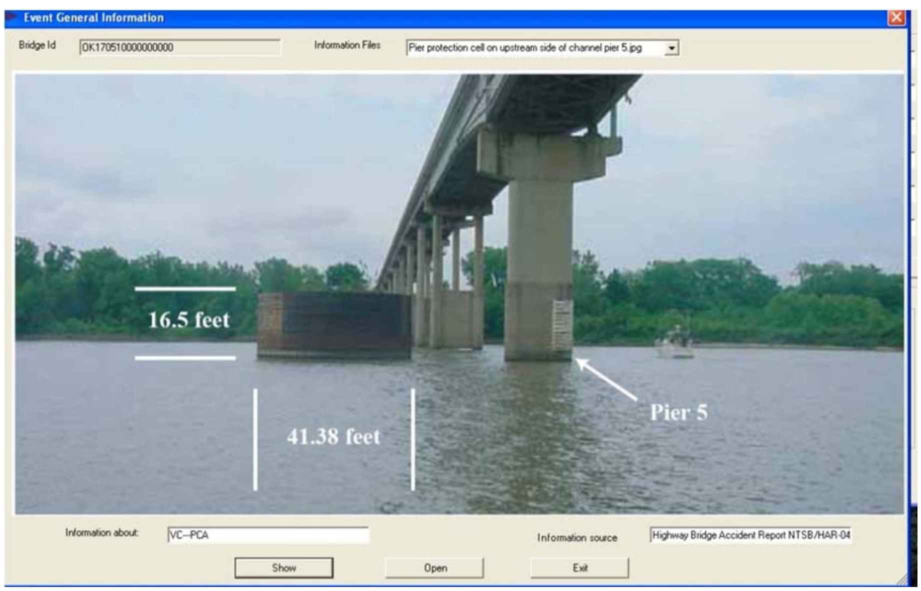
This part includes the event, basic information about the bridge, navigation and vessel collision information.Like the flood/scour hazard section, there is common information for all hazards and bridge detail information.

a) Navigation and vessel information

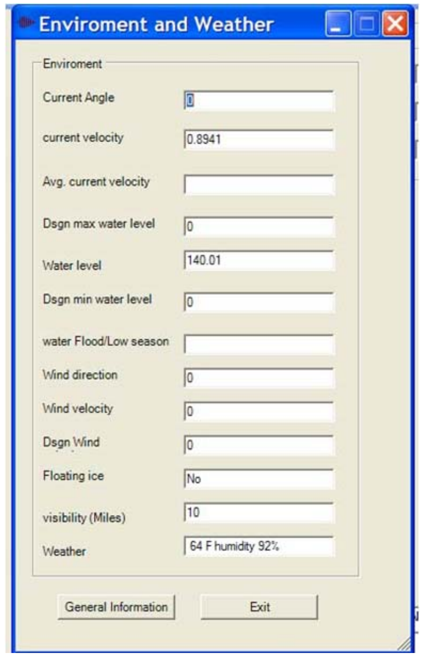
- Pier, pier channel and impact information interface



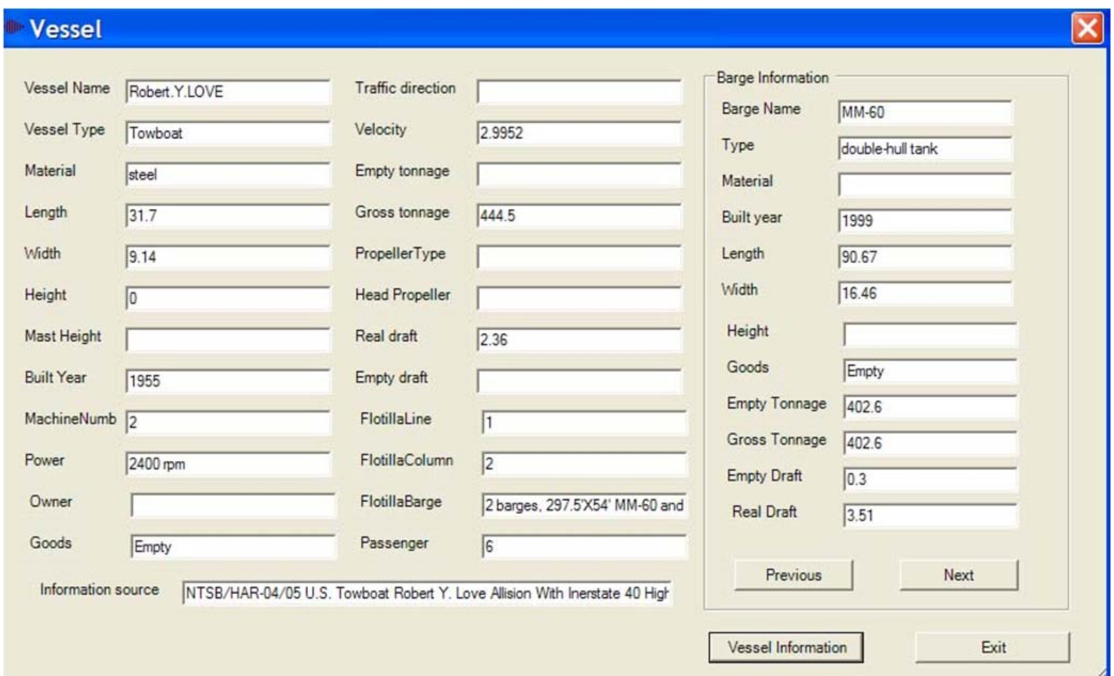
- Impact general information (from the pier, pier channel and impact information) interface



- Bridge environment and weather information interface



- Vessel and barge information interface

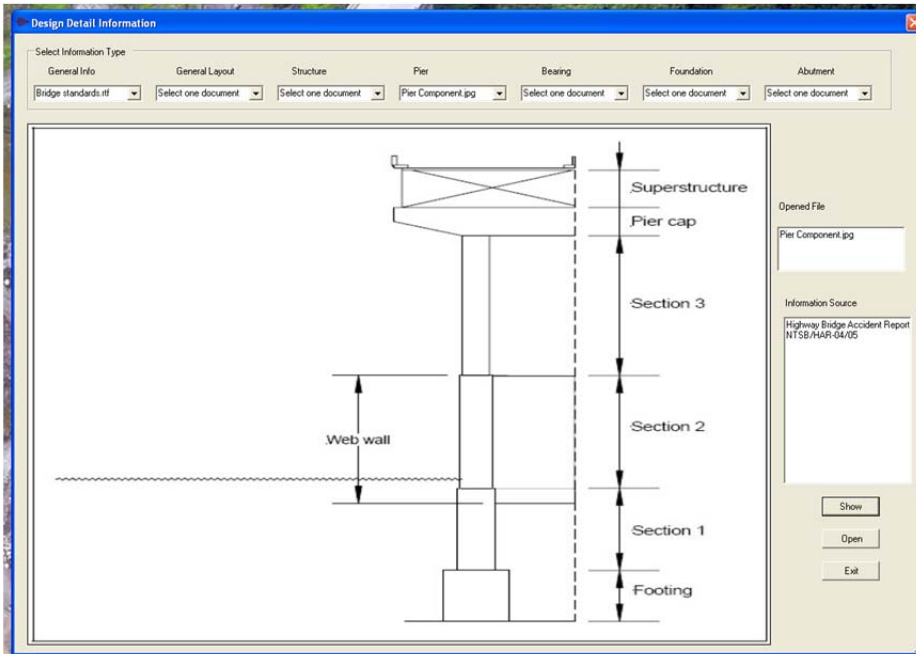


General information about the vessel (from vessel information) interface

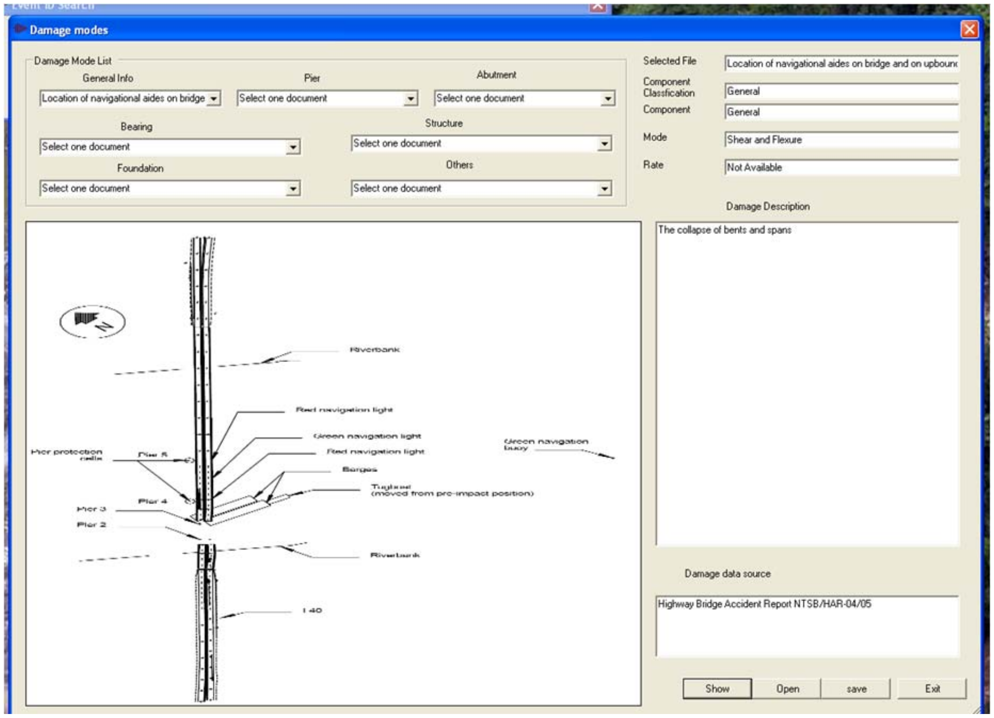
b) Bridge detailed information.

Similar information is included in the vessel collision section as in the flood/scour section.

- Design information interface



- Damage information interface



A.2 Instructions for Using the Program

- User interfaces for flood/scour, earthquake and vessel collision are provided herein. Other hazard information has not been obtained so those interfaces are still under development.
- General information is included for almost all the interface windows. All the information related to the property is collected and shown in the window.
- For each general information file, “show” and “open” operations can be selected. The “show operation” shows the file in the window, and can only open ‘jpg,’ ‘txt,’ ‘rtf,’ files. Files with extensions of ‘doc,’ ‘ppt,’ files cannot be opened in the software window; they only open if Microsoft Office is installed.

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