STATE OF CALIFORNIA
CALIFORNIA DEPARTMENT OF TRANSPORTATION

PB2000-102477

RESEARCH PROJECT F94SD38C

DEVELOPMENT AND EVALUATION OF A FIELD COMPUTER SYSTEM FOR BRIDGE MAINTENANCE INSPECTIONS

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Engineering Service Center

Office of Structure Maintenance and Investigations

December 1998

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

1. Report No. FHWA/CA/ESC - 99/15	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DEVELOPMENT AND EVALUATION OF A FIELD COMPUTER SYSTEM FOR BRIDGE MAINTENANCE INSPECTIONS		5. Report Date December 1998 6. Performing Organization Code
7. Authors Michael B. Johnson		8. Performing Organization Report No. F94SD38C
9. Performing Organization Name and Address California Department of Transportation New Technology and Research, MS-83 P.O. Box 942873 Sacramento, CA 94273-0001		10. Work Unit No. 11. Contract or Grant No. 59A023
12. Sponsoring Agency Name and Address California Department of Transportation Sacramento, CA 95819		13. Type of Report and Period Covered FINAL 14. Sponsoring Agency Code

15. Supplementary Notes

This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This report explores the use of current technology to improve the efficiency of bridge inspection information collection and processing while improving emergency response efforts by providing bridge inspectors access to data and images from remote bridge sites. The key components of a remote access system are outlined and a detailed comparative review of the four major methods of obtaining remote access are discussed in detail as they apply to bridge inspection. The required hardware and software requirements for implementation of a remote access system for bridge inspection are also outlined.

Improvements in the efficiency of processing and reporting of bridge inspection results are presented illustrating the potential benefits of the application of current technology to the bridge inspection process.

During the research project, it was quickly realized that a custom developed bridge inspection software application incorporating bridge report generation could significantly reduce the time required to complete a bridge inspection and reporting process. In light of the strong potential benefits, the Office of Structure Maintenance and Investigation began a concurrent implementation project that tracked the progress of the ongoing research project.

17. Key Words Bridge Inspection, NBIS, Pontis, Remote Access	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72)

FINAL REPORT

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ACKNOWLEDGEMENTS

The author would like to acknowledge Mandar Bokar, Mary Beth Harrow, Sujay Jalihal and Steve Morris of the Oracle Corporation for their insight and hard work during this project. A special thanks to Evan Evans of the California Department of Transportation for his help and guidance throughout this project. Thanks also to the many dedicated employees of the California Department of Transportation for their expertise, hard work and patience during this research and subsequent implementation effort.

INTRODUCTION

The California Department of Transportation is responsible for routine bridge inspection and report development on over 25,000 structures statewide. Structures carrying vehicular traffic in excess of 6.1 meters in length are typically inspected once every two years. The inspecting agency is responsible for collecting and reporting over 100 inventory and condition items for each structure as required under the National Bridge Inspection Standards (NBIS). The data processing demands associated with bridge inspection is common to all states as well as agencies outside the United States. Manual collection and processing of this data is extremely cumbersome resulting in inventory data errors and delays in transmitting bridge inspection reports.

This report explores the use of current technology to improve the efficiency of bridge inspection information collection and processing while improving emergency response efforts by providing bridge inspectors access to data and images from remote bridge sites. The key components of a remote access system are outlined and a detailed comparative review of the four major methods of obtaining remote access are discussed in detail as they apply to bridge inspection. The required hardware and software requirements for implementation of a remote access system for bridge inspection are also outlined.

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During the research project, it was quickly realized that a custom developed bridge inspection software application incorporating bridge report generation could significantly reduce the time required to complete a bridge inspection and reporting process. In light of the strong potential benefits, the Office of Structure Maintenance and Investigation began a concurrent implementation project that tracked the progress of the ongoing research project.

PROBLEM STATEMENT

Manually collecting and processing bridge inspection data required to conform to the National Bridge Inspection Standards (NBIS) is cumbersome and results in unnecessary data errors and delays in transmitting bridge inspection reports.

Bridge inspectors have no means to retrieve or transmit bridge inspection information from remote field locations as required for post earthquake assessments.

BACKGROUND AND LITERATURE SEARCH

The California Department of Transportation (Caltrans) has the responsibility for gathering and processing the bridge inspection information for over 25,000 structures. The information is collected by approximately 40 bridge inspectors working for Caltrans as well as inspectors for several other Agencies within the State. In total there are over 6 million items of bridge data and images maintained by the Department. The data demands of the bridge inspection program are not unique to Caltrans, the Federal Government requires all states to gather and process bridge inspection data in accordance with specific regulations.

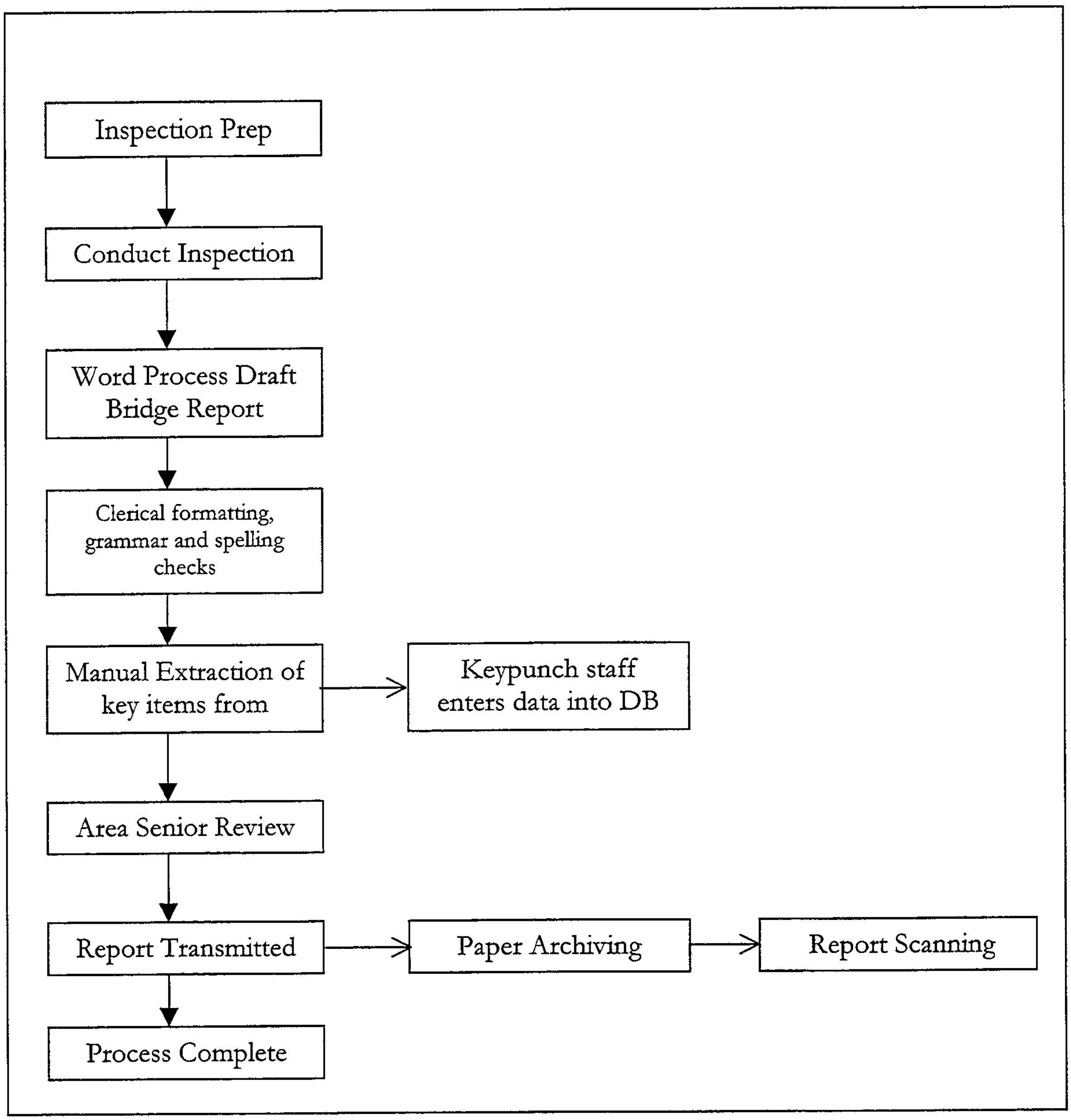
Caltrans performs bridge inspections from three branch offices within the state. The Sacramento branch has 20 full time bridge inspectors and five area senior engineers that are responsible over 15,000 inspections on eligible structures in the northern 43 counties of the state. A branch office in Los Angeles is staffed with nine bridge inspectors and two area senior engineers that perform over 7,000 inspection in the lower 15 counties of the state. Caltrans also staffs an inspection branch in Oakland that is responsible for the inspection of the nine major toll bridges in the San Francisco bay area. In addition to the bridge inspections performed by Caltrans, four local agencies within California perform inspections on the locally owned structures within their jurisdiction. On average, each Area Bridge Maintenance Engineer (ABME) is responsible for inspecting and writing bridge reports for approximately 30 bridges per month or 360 bridges annually. The goal of this research was to pilot ways that technology could be used to improve the overall efficiency of the bridge inspection, Federal coding, reporting and data manipulation processes.

To appreciate the potential efficiency increases this research project carried, it is important to understand the bridge inspection requirements and the procedures for manual processing of this information. To prepare for each manual bridge inspection, the ABME must review historical records, compile outstanding work recommendations, review contract and design status information and collect all pertinent condition and inventory information required under the National Bridge Inspection Standards (NBIS).

A typical inspection trip will consist of one week of field inspection work on approximately ten different bridges. The size and complexity of the bridges to be inspected could substantially increase or decrease the number of bridge inspections completed during the field inspection time. On return to the office, the ABME prepares a draft bridge inspection report. This report consists of updated condition and inventory information. In many cases the change in the condition of the structure results in the need for new work recommendations, load capacity analysis or scour analysis.

The draft report is typically prepared by the ABME using a laptop computer in the office. The draft report would be prepared in a word processing software program and forwarded along with the original file to the clerical unit for final formatting, grammar and spelling checks. Once the draft final report had been printed out, it was forwarded to a Federal coding unit that manually extracted the work recommendations, element inspection information and NBIS inventory items. The manually extracted information was placed by hand onto keypunch forms for later entry into a mainframe database. After the coding was complete, the report was forwarded to the area senior engineer for final approval. The area senior engineer reviewed the report for content and accuracy. If the area senior had comments or corrections, the hard copy report is returned to the ABME for correction and re-submittal. If no corrections were required, the final reports were forwarded back to the clerical unit for transmittal, archiving and scanning (Fig. 1).

Figure 1 - Existing Bridge Report Processing Flowchart



Once the bridge inspection information had been keyed into the mainframe, the information was virtually inaccessible by the inspecting engineers for any data manipulation or search usage. The entire process from inspection to report transmittal would take from one to four months. It was apparent that the existing method utilized for processing the bridge inspection information was cumbersome and could be significantly streamlined through the use of technology.

At the time of the original research proposal a survey of existing software for bridge inspection was conducted. Several known commercial software packages for this type of work were available, but none provided the necessary functionality without significant modification. In addition to commercial software programs, several state agencies had developed software packages for bridge inspection. In all cases these software programs provided no post-earthquake inspection capabilities essential in California. For these reasons, Caltrans opted to develop a custom software application.

OBJECTIVES

The project objective was to research ways to increase the collection efficiency of the bridge inspection information and to provide field retrieval and transmittal of bridge inspection data. This effort carried the potential to streamline a manual data handling process, increase the quality of the bridge reports, and reduce the staff necessary for processing bridge reports. One area of expected benefit was very rapid report turn around time for routine inspections and in emergency response situations.

SCOPE

The project scope was to develop a computer software application that would allow Area Bridge Maintenance Engineers (ABME) to "call up" bridge design, construction and maintenance information from a remote sight using a laptop computer. The project also provided for the remote transmission of critical bridge inspection information obtained during major emergency response efforts to a network server. The software had to provide all Federal coding of the bridge inspection data and complete report generation capabilities.

TECHNICAL DISCUSSION

SYSTEM BACKBONE

To effectively implement a system for remote access it is essential to have a stable network foundation to build from. When evaluating the available options for remote access for bridge inspection information is important to consider such items as hardware platform, operating system, database engine, network capabilities, and data sharing between units prior to the start of any software design effort.

NETWORK

The minimum requirements for an automated system for bridge inspection include a database server and a single client. The connection between these two computers may be as simple as a modem or as permanent as a hardwire Ethernet connection.

Caltrans has an extensive computer network that connects all 12 districts and the headquarters offices together. Having this network backbone in place prior to this research project afforded great flexibility in system design. The Caltrans wide area network consists of a Novell NetWare network connecting all major work groups servers together over a wide area network.

OPERATING SYSTEM

There is virtually no limitation on the operating system that can be used for the development of a remote access system. One of the presented solutions for remote access will work on all major operating systems without programming changes. Recent advances in HTML and JAVA programming are making the client operating system less of a dominating factor than in the recent past.

Within the Caltrans Office of Structure Maintenance and Investigation it was opted to use Windows based operating systems all for client machines. A Typical client machine runs Windows 95 or NT, operates at 200+ MHz and has 64 MB of random access memory. The operating system was mandated by Office policy and was not evaluated against other competing operating systems during this project.

FIELD COMPUTERS

Several options exist for the field computers used by the bridge inspectors. Pen based computers were evaluated as an option for field inspection activities. This research project was not geared toward the evaluation of all competing pen based units but rather the applicability of this technology as it pertains to bridge inspection. The Fujitsu Stylistic was selected for evaluation of pen technology. The Fujitsu was selected because it had full computer processing and storage capabilities, was relatively small, and had good screen visibility in an outdoor environment. The poor handling of text entries either through hand writing recognition or on screen key board led to less than satisfactory overall performance of the pen-based computer. The Fujitsu model tested does have a plug in conventional keyboard for text entry but then becomes far less portable.

Conventional laptops are typically larger and less manageable then pen based units but are more affordable and have standard components. The standard battery and other components are an important consideration due to the potential failure of equipment and the availability of replacement parts. Ultimately standard laptop computers were preferred over pen-based computers.

Palm type machines have been used to a limited extent for bridge inspection work. These machines are typically far less expensive than either pen based or laptop computers but have limited processor, storage and communication capabilities. Palm type computers were not considered for this project because of these limitations.

During the project we noticed that bridge inspectors prefer not to use any computer during the actual physical inspection. The preferred scenario was to have a detailed printed pre-inspection report, a piece of paper, generated by the system for use during the field inspection. The pre-inspection report provides location, construction, condition, utility, and roadway information as well as element inspection information and notes.

DATABASE ENGINE

A central database that contains all bridge data and images is a requirement of all remote access methods. A specific brand of database engine is not required but attention should be given to the overall goal of the project and the capabilities and limitations of the selected engine.

The database engine used for this project was the Oracle 7.3 engine. This engine was mandated by department policy to provide uniformity between all "corporate" databases. The database engine was served by a SUN server running the UNIX operating system. No comparisons were made between the major competing database engines or database server operating systems.

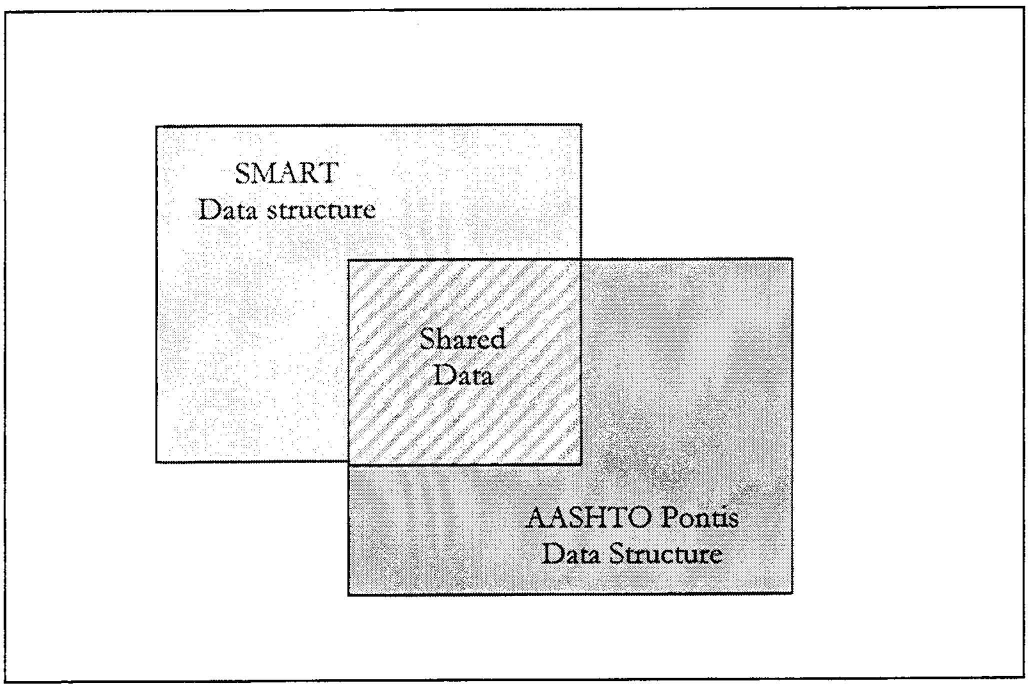
DATABASE DESIGN

The database design is a critical step in the development of any remote bridge inspection application. In bridge inspection circles we have a huge advantage because all states must comply with the National Bridge Inspection Standards (NBIS) and the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges. The Coding Guide defines each required field and the exact attributes of the items. In addition to the items defined in the Coding Guide, California tracks many other items necessary to properly manage the bridge inventory.

Once the extent of the data items is defined, the relationships of all items to each other must be developed. The process of defining the entity relationships is a considerable task. Because of the effort involved in creating a database of the complexity necessary for bridge inspection, Caltrans opted to build onto the database structure defined by the AASHTO Pontis program already in use in California.

Since the Pontis program was already in use within Caltrans, it made sense to utilize the existing database structure of Pontis for all the items defined within the Pontis database. The Pontis data structure had a proven design for all NBIS items as well as bridge management structure required by Pontis for deterioration simulation and optimal project selection. Tables were added to the Pontis data structure as necessary to meet Caltrans specific needs.

Figure 2 – Shared Database Design



Building on the Pontis data structure saved considerable time in the ultimate implementation of the custom developed software dubbed the Structure Maintenance Automated Report Transmittal System (SMART) application. This shared database design concept allows either Pontis or SMART to be used to update all NBIS items. Pontis has sole access to the deterioration models, improvement models, expert elicitation's and Pontis system management tables. SMART has sole access to detailed post earthquake, scour, load rating, permit, project tracking, fracture critical and underwater investigation tables (Fig. 2). By choosing this "shared database" structure, no data movements between SMART and Pontis would be required.

An additional benefit to using the shared database design is that most State Department of Transportation's are using the Pontis program allowing sharing of bridge, inspection and roadway reports and data without modification. Using the shared database structure allows Caltrans to produce data interchange files from Pontis to facilitate the transfer of bridge inspection data between Caltrans and any other agencies using Pontis. The data exchange capability was considered essential to allow data movements between Caltrans and the four local agencies within California using Pontis to perform their own inspections.

REMOTE ACCESS

One of the main research objectives was to pilot a way for bridge inspectors to access past inspection data, transmit new inspection findings and view bridge plans from a remote site. The need for this capability became apparent during the emergency response efforts following the Northridge earthquake. Caltrans managers needed rapid reporting of post earthquake inspection information to ascertain the current status of the bridges on each major freeway within the area and to prioritize where equipment, materials and crews were needed for repairs.

During the course of this research we explored three methods for providing the remote access to bridge data and images; database replication, client server software running over a dial-up network connection and web based solutions.

DATABASE REPLICATION

Database replication is a technology that allows a bridge inspector to take an exact copy of a database into the field for use. All changes made to the local database are tracked within the database for future updating to a central database. A bridge inspector is unrestricted in the type and number of changes they can make while operating on the local database. Using the replication technology, an inspector would typically take a laptop or pen based unit into the field and perform all necessary edits and updates to the data using the local database. Under normal circumstances the inspector may perform a week or more of field work before replicating the changes to the central database. There is no technical restrictions placed on the time between replications, but an agency opting for this technology should set practical time limits to avoid possible data conflicts.

Replication technology has an advantage over the other methods of remote access in that no modem connection to the central database is required to run a stand-alone application from a remote sight. This can be a major consideration for regions without adequate phone access. When it becomes necessary to replicate from a field location, such as needed during earthquake response, replication requires a phone line to establish a dial up network with the central database.

Replication carries with it a large data management responsibility. In Caltrans we may have over 35 bridge inspectors in the field performing bridge inspections on different local databases. Having this many copies of the database requires tools to manage the potential data conflicts and to verify that the field edits made have actually been replicated. The process of verifying that all the data was replicated properly is very difficult to manage. The database procedure performing the replication must specify how the database is to handle data conflicts.

For example if an inspector in the field performing an inspection observes changes in the scour criticality of the bridge and changes the item 113 code on the local database to a 2. While the inspector is in the field performing additional inspections, someone in the office working on the central database has just finished scour calculations that indicate an item 113 code of 5. The office staff immediately updates the central database to reflect the change in the scour code based on the calculations. Upon replication of the field data, the database will experience a data conflict because the scour item the field inspector is trying to update has been changed since the last replication of the inspectors' local database. The database must have set rules for handling this type of problem. For the example presented it would be extremely difficult to define rules to allow the database to resolve this conflict. Most likely someone would have to manually track down who had made changes, what the values were and which one the database should be updated with. It is the management of the data that ultimately led Caltrans away from this technology for remote access.

The replication method also has technical limitations pertaining to retrieval of image files. With this technology, all images within the image database would have to be carried on each laptop. It is technically possible to perform a "snapshot" load of the image files but it is not practical to store all the image files on a laptop. In California the image snapshot would be approximately 120 gigabytes in size. This limitation in handling images was considered a drawback with replication technology.

CLIENT SERVER APPLICATION OVER DIAL UP NETWORK

Running a client server application over a dial up network is one method of avoiding the data management problems associated with replication. With this technology, an inspector at a remote sight can use a modem and phone line to establish a dial up network. A dial up network allows the user to run most applications as if they were sitting in the office operating on the network. Once the dial up network is established, a client application can be run while connected to the central database.

The limitation to a dial up solution is that the operating speed of the client application is often limited by the speed of the modem. An additional drawback to the dial up network is that it requires a land based phone line and modem to work reliably. Current cellular technology actually sends small packs of information in intermittent streams that reduces reliability during large data movements. Technology advancements in the area of cellular phones, cellular modems and direct satellite phone connections are rapidly chipping away at this limitation. It is quite likely that within the next several years cellular, digital or satellite phone dial up network connections will be effective for running client server applications from remote locations.

A client server solution operating over a dial up network allows access and updates of image files from a central database. With this technology no storage of images is required on the field computers. The upload and download speed of the modem becomes a bottleneck in the overall system performance. Depending on the speed of the dial up connection, it may take up to 5 minutes to download a detailed full size plan sheet.

The client server technology requires that the remote inspection application be resident and operated on the field computer. It is essential that all field computers have the identical version of the program. This means that someone must be responsible for updating all field computers when any database or application change occurs. Depending on the number of software copies and physical distribution of the field computers, this may be an onerous version control task.

WEB SOLUTIONS OVER DIAL UP NETWORK

The third option for remote operation that was explored was the use of web based programming (html, SQL and Java) operating over a dial up network. This approach only requires the field computer to have dial up network capability or Internet service provider connection and an Internet browser to operate. This option has the benefits of operating off a central database eliminating the data conflict drawbacks seen with replication.

The image handling capabilities of the web solution are essentially the same as the client server options. The bottleneck of the modem connection speed and the need for a land based phone line as detailed in the client server option also exist for the web solution.

One key advantage the web solutions offer is that the remote application is being served from a network server and therefore requires only an Internet browser on the field computer. This advantage greatly reduces the version control issues faced by the client server approach. Changes in the program or database can be made with virtually no required changes on the field computers. This solution also has the benefit of being the only solution that can operate on all major operating systems without modifications in programming. In California the web solution was considered superior to other approaches because it met the requirements established for remote access while minimizing the overhead associated with the maintenance of the application and database.

FILE TRANSFER BETWEEN FIELD AND CENTRAL DATABASES

File transfers of field information to central database is an additional option for field operation that has been used in other agencies performing bridge inspection work. This option was not researched as part of this project as the pros and cons are sufficiently documented by applications using this approach. This technology utilizes a client inspection application running on a stand alone field computer. A database of bridge data must be resident on the field computer. Using this technology, an inspector would "check out" a subset of bridges from a central database and load the subset database into the field computer. The inspector would then operate the field computer completely independent of the central database. Depending on the application, the bridges that have been "checked out" may be frozen for update by other clients using the central database until the "check out" file is returned to the central database. If the application does not freeze the "check out" bridges, data conflicts similar to those seen with database replication are likely. After making all necessary field edits to the data, the "check out" file of data is uploaded to the central database.

It is possible to perform the "check in" and "check out" process over a dial up network connection or by e-mail to office personnel for update. One benefit this techniques has is that only small subsets of the large central database need to reside on the field computers. This method requires a land-based phone line and dial up network or Internet access to operate from a remote bridge sight. A moderate level of data management is required with this method to assure that database subsets that are "checked out" are checked back in. If the application freezes the checked out bridges in the central database, office personnel will be prevented from performing any updates to the data for those bridges until they are returned.

The file transfer method of remote access cannot view as built images unless they reside on the field computer without the use of a land based phone line and access to a central database. File transfers of image files is very cumbersome and offers no advantage over client server or web-based approaches.

Figure 3 - Summary of Remote Access Techniques

System Attribute	Replicate	Client Server	Web based	File Check Out
Requires Exact Copy of Entire Database on the Field Computer	X	N/A	N/A	
Allows Subsets of the Entire Database on the Field Computer		N/A	N/A	X
Data Access Without Phone Line	X			X
Data Access With Phone Line Only		X	X	
Complete Image Access Without Phone Line				
Complete Image Access With Phone Line	X	X	X	X
High Potential For Data Conflicts	X			X
High Data Management Effort	X			
Moderate Data Management Effort				X
Low Data Management Effort		X	X	
High Version Control Effort	X			
Moderate Version Control effort				X
Low Version Control Effort		X	X	
Application Runs on Field Computer	X	X		X
Application is Runs on Network Server			X	
Operates on All Major Operating Systems			X	

APPLICATION DESIGN

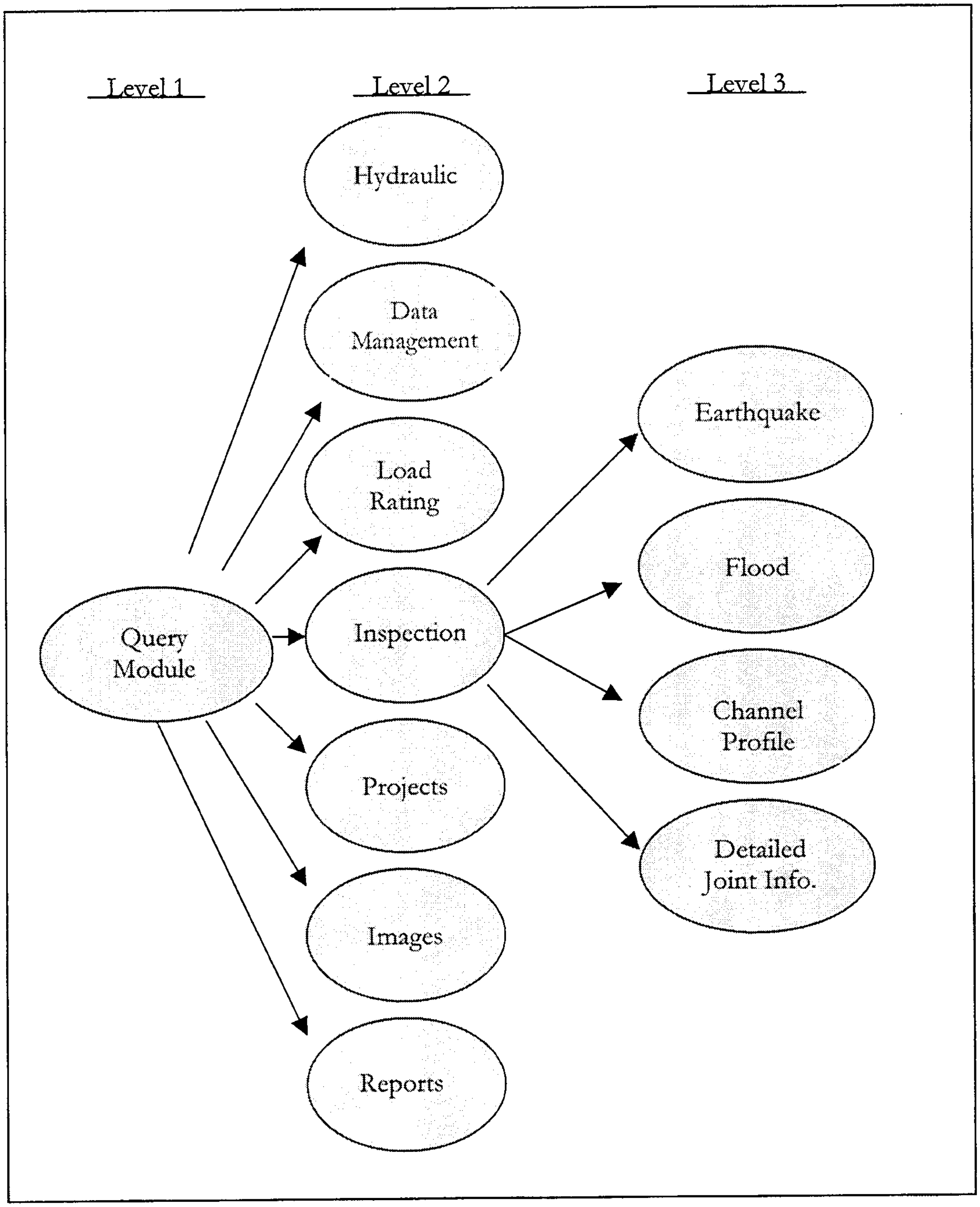
At the time of the original research proposal a survey of available software for bridge inspection was conducted. Several known commercial software packages for bridge inspection were available, but none provided the necessary functionality without significant modification. In addition to commercial software programs, several state agencies had developed software packages for bridge inspection. In all cases these software programs provided no post-earthquake inspection or image access capabilities essential to Caltrans. To meet the objectives of this research project, it was apparent that a custom software application would have to be developed.

All methods of remote access explored require a software application to operate. The options available for software development are numerous. Programming tools such as Microsoft Access, Sybase Powerbuilder, Oracle Developer 2000 and many others are available for use. The focus of this research was not to provide a comparison between tools but to evaluate the applicability of the technology.

Once the database design had been finalized, work on the application was begun. Oracle Developer 2000 software was ultimately selected for the application because of its compatibility with the Oracle database engine, flexibility in compiling platform and overall robustness of the program capabilities.

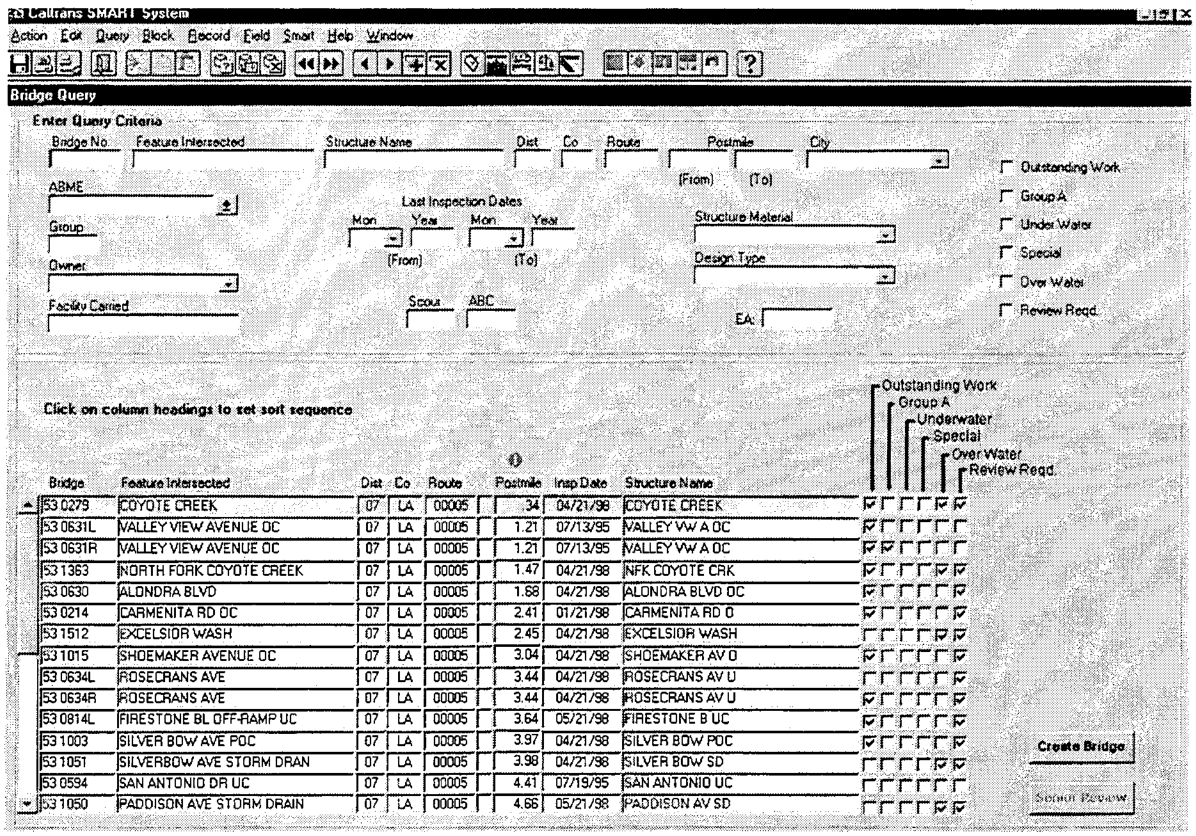
The application navigation process was the first item developed. Borrowing the concepts used by programs such as Pontis, we opted for module type navigation. Navigation was restricted to two screen levels from the main module. All navigation within the application would move through the main module to facilitate training and use of the application (Fig 3). This navigation scheme also minimized the programming required to handle between module navigation.

Figure 4 – SMART System Navigation



Once the navigation plan had been decided, Practicing bridge inspectors were utilized to develop screen layouts that were most conducive to their field work. The query screen was developed to provide an interface for locating bridges to work with.

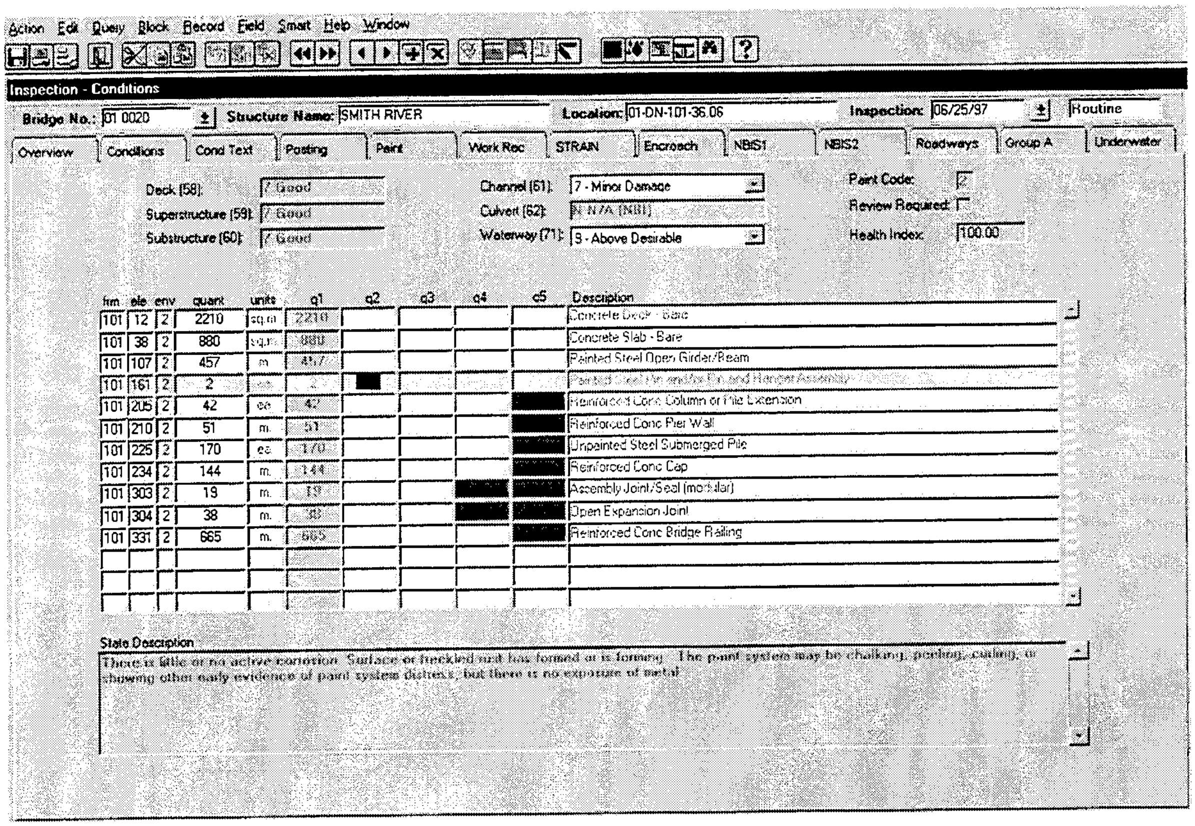
Figure 5 – The SMART Query Screen



The query screen is a split screen with the top portion providing the criteria for retrieval of bridges from the database and the bottom portion displaying the results of the database query. Figure 5 is showing the results of a query of route 5 in Los Angeles County with the results sorted by ascending postmile. Any combination of the items from the top portion can be used to query bridge records from the database. The check boxes on the top portion can also be used as search arguments. The results of the query show the bridge identification, location information, inspection dates and check boxes for bridges with outstanding work, fracture critical designation, underwater inspection requirements, special inspection requirements or report review pending. The query screen also acts as the launching area for all other modules of the application. Once the engineer has developed a group of bridges to work with, these bridges will be available in all other modules of the program.

The most heavily used area of the application is the inspection module. The inspection module is the location where the majority of all text and data are entered into the database. The inspection module is comprised of 13 tab screens organized to facilitate the bridge inspection process.

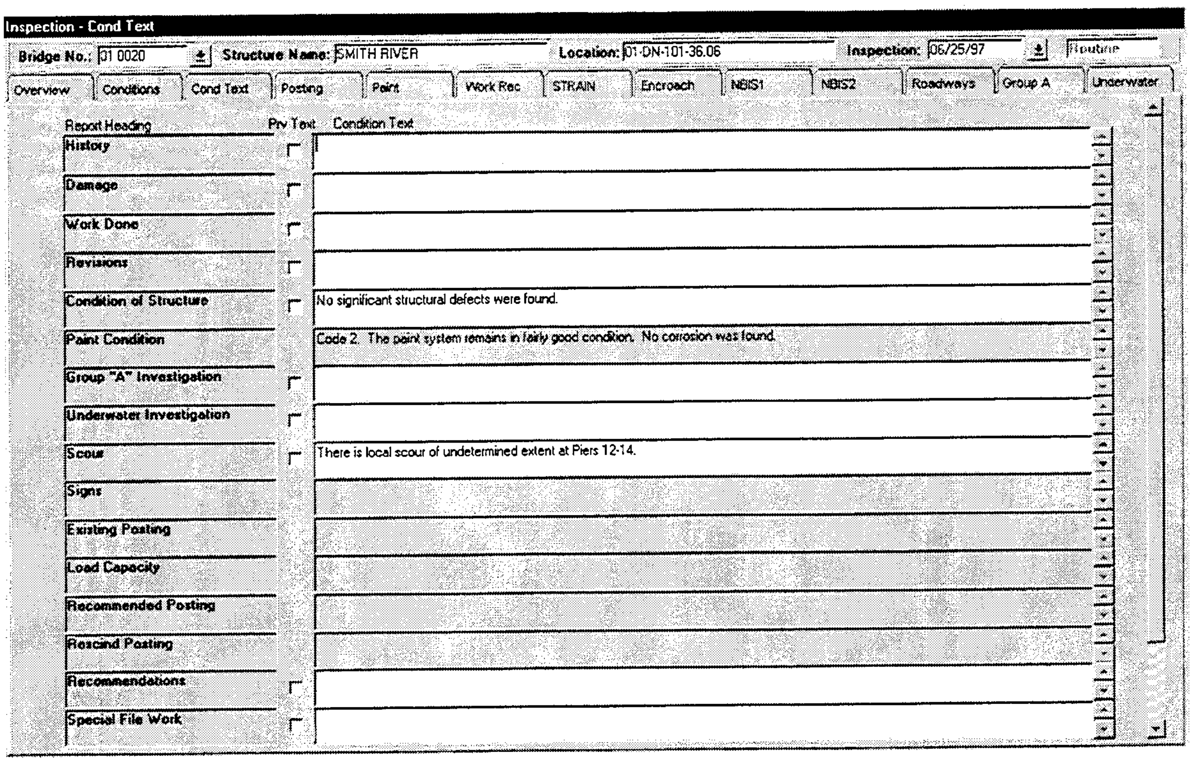
Figure 6 – The Inspection Module



The inspection module has several innovative features designed to increase the efficiency of the inspection data entry. On the condition tab the elements and the NBI condition ratings are displayed together. The SMART application performs dynamic element translation to NBI condition ratings using a stored database procedure derived from the converter developed by the University of Colorado. The complete element inspection condition state description is dynamically displayed in the lower "state description" box as the mouse is moved from one condition state to another. On the fly quantity changes and element quantity summations are utilized to ensure that no field addition is required to ensure that all element quantity is accounted for. The bridge Health Index is also dynamically calculated and displayed for the inspector to review. This single screen provides the bridge inspector with a good overall picture of the condition of this structure. All but two items on this screen reside in the portion of the database shared with Pontis.

Bridge inspection reports generated by Caltrans engineers rely heavily on text entries to document the current condition of a bridge. To facilitate text report entry, the condition text screen was developed around the standard bridge inspection report headings used in Caltrans. The seamless inclusion of text was considered essential to the overall success of the SMART program. It was clear early on in the development that all text entry fields must have spell check capabilities. To satisfy the need for spell checking of text fields, Microsoft Word was designated as the default editor for all text fields. This feature provided bridge inspectors an option double clicking any text field to "send" the contents to MS Word for spell checking or use Word to develop the entire text entry and have it "sent" back to the database field on exiting Word. The spelling and grammar check features of Word were seamlessly integrated with the SMART software using the developer 2000 development tools. The condition text screen also provided the capability for inspectors to "copy" the entries from prior inspections, on a field by field basis, into the current inspection. This feature eliminated the typing required for repetitive text entries. Having this feature active on a field by field basis provided the greatest flexibility in the overall usefulness of the copy functionality.

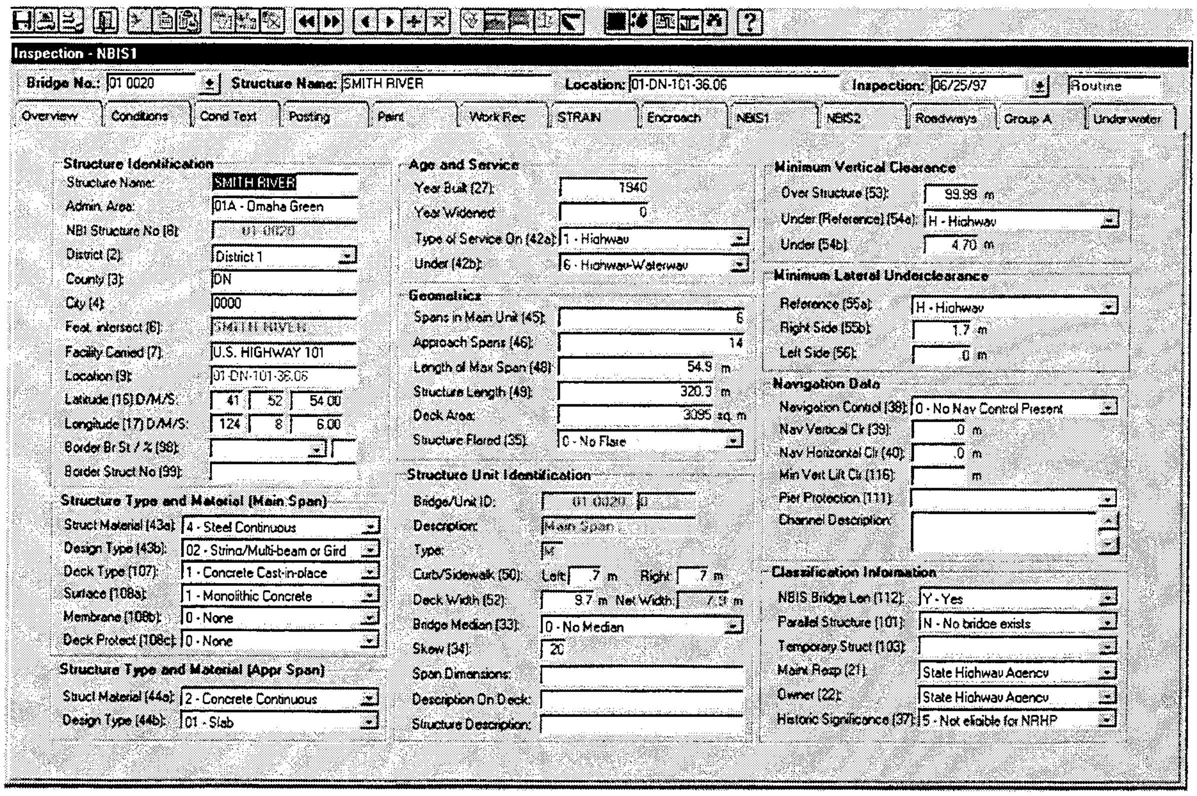
Figure 7 – Condition Text Entry



To minimize screen usage, a small scrolling window is associated with each text heading on the left. While the screen space allocated to these fields appears small, the fields can handle up to 18,000 characters each. Viewing of large text entries is possible by double clicking on the text field to invoke MS Word and viewing full screen. The text entered into any of the above fields is ultimately generated onto the final bridge inspection report under the appropriate heading. While operating SMART it is possible for the text of any prior inspection to be reviewed online or printed out for reference. The Developer 2000 software used to develop SMART supports standard Windows cut and paste operations further minimizing retyping of information.

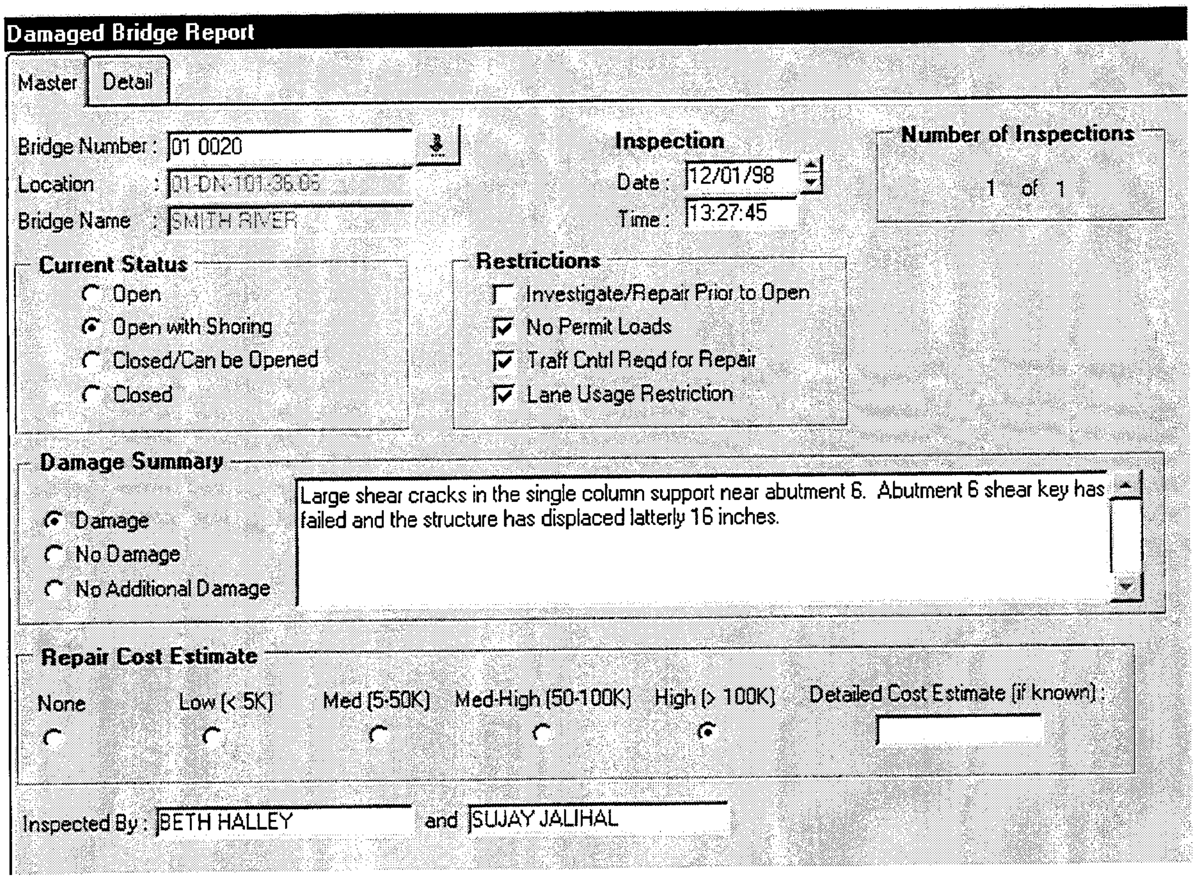
The screen layouts in general reflect the desire of the bridge inspectors to have minimal screen movements. Most bridge inspectors preferred screens that have a fair amount of information without a cluttered look. Within SMART there are several screens that demonstrate this concept well. One of the NBIS screens contains a large number of data items but the presentation of the information was preferred to several screens with fewer items (see figure 8).

Figure 8 – National Bridge Inspection Data Items



One of the goals of the project was to provide a means to quickly transmit post earthquake inspection information to central database. To accomplish this goal, a form Caltrans had refined during past earthquakes was mimicked on screen.

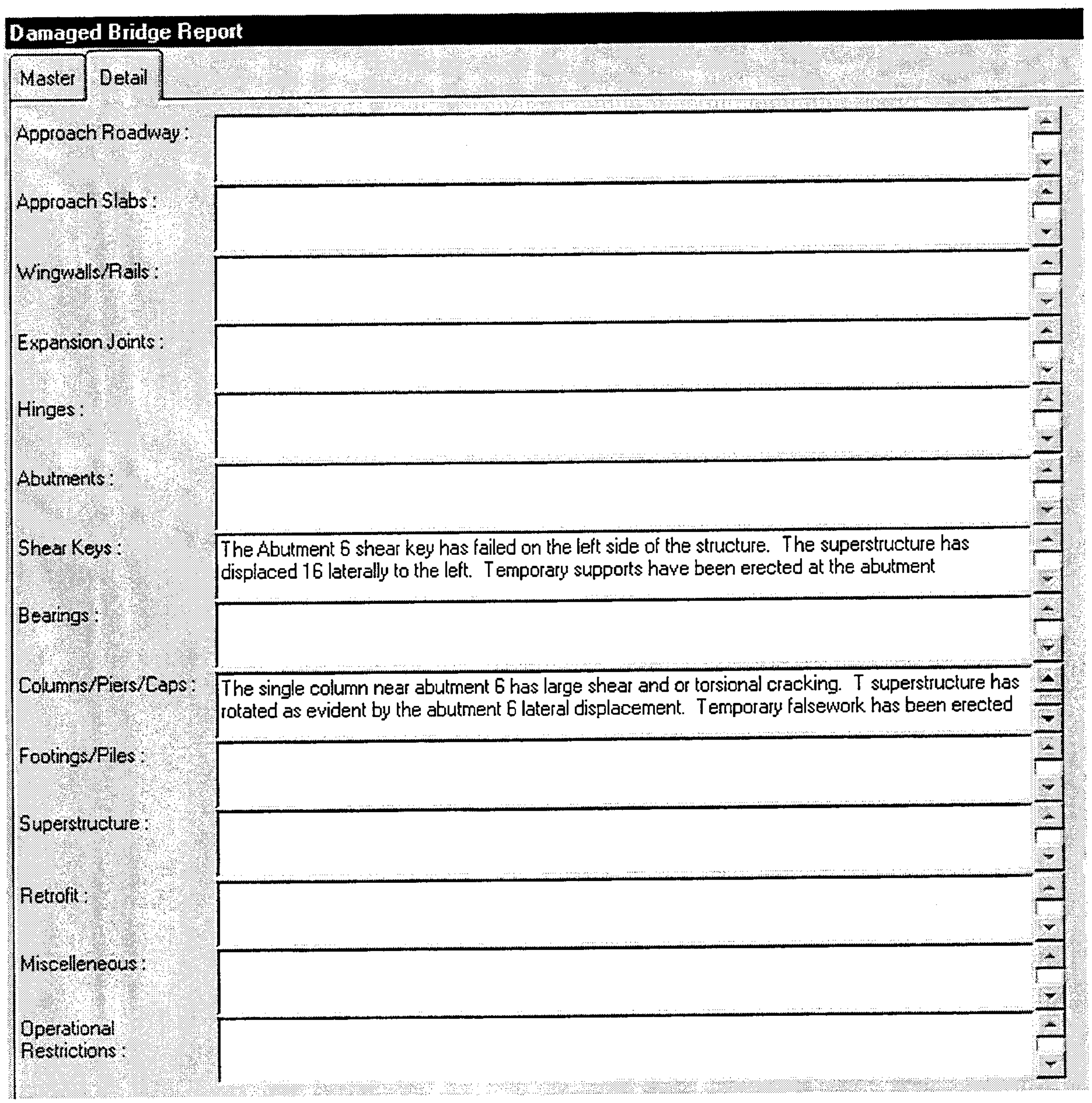
Figure 9 – Post Earthquake Inspection Screen 1



The post earthquake inspection screen provides an interface for bridge engineers to record the damage associated with a major seismic event. This form captures each inspection by bridge identification, date and time of inspection. Though Caltrans has developed quite a reputation for efficient response efforts to major seismic events, there is inevitably some miscommunication between the large number of personnel responding to a large earthquake. In the past bridge inspection information would not be available for at least 12-18 hours and in some case longer. SMART offers the flexibility to immediately update the central database with the results of an inspection. Following a major event, it is very common to get a large number of people calling into the department reporting all sorts of damage to bridges. These reports from the public have caused inspection teams to be dispatched to a particular site to ensure the public safety. In some cases the structure may have been inspected once already but the inspection information had not made its way to the central database. SMART eliminates the problems associated with multiple inspection on the same day by storing each inspection independently by date and time. This allows a manager in the command center to see a chronological listing of all inspections performed. The chronological listing of all inspections also provides a way to track the operational status of the bridge and the roadway.

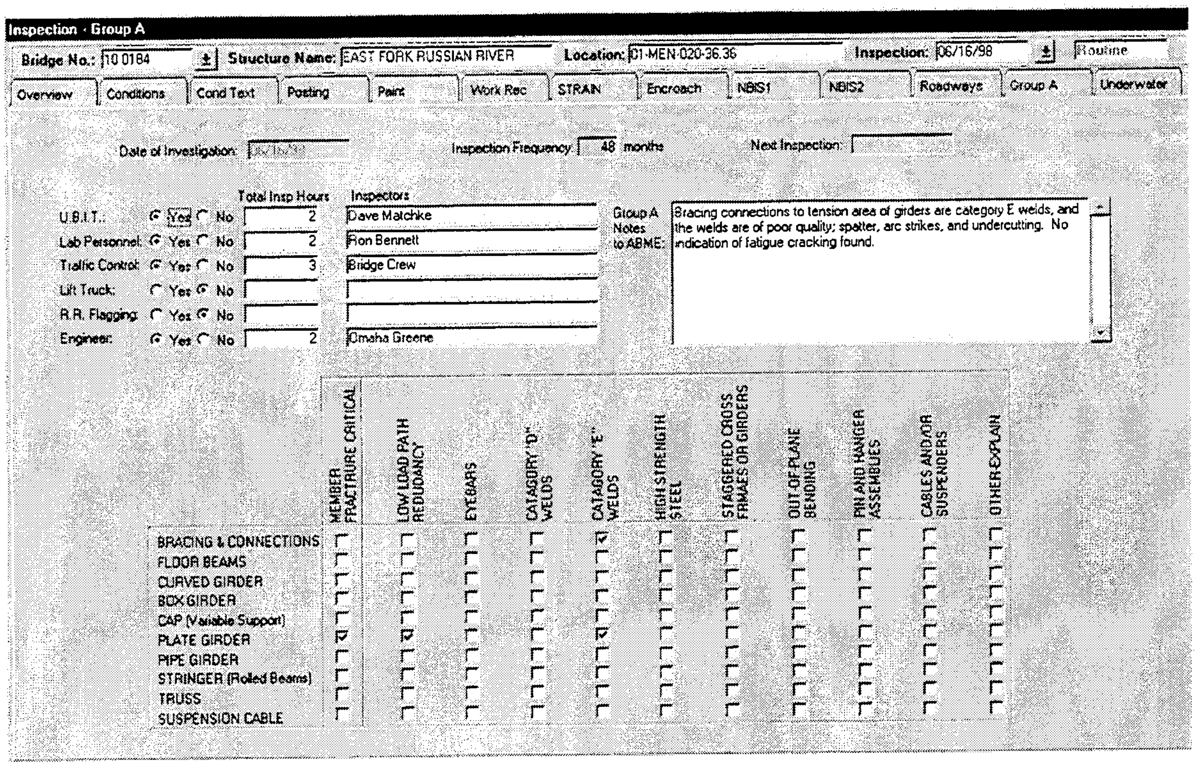
Much like the typical bridge inspection report, a post earthquake inspection report relies heavily on text to describe the current condition and to describe any repair needs. Figure 10 shows the text entry screen for post earthquake inspections. During this special type of inspection, the components of the bridge are broken into element types that are different than routine inspections. The alternative element breakdown has proven to be quite effective during responses to prior earthquakes. Associating the post earthquake data with the inventory attributes from the database provides the department with complete ad-hoc report capability on almost any bridge aspect or attribute desired.

Figure 10 – Post Earthquake Inspection Screen 2



To improve Caltrans ability to respond to emergency situations, several additional features were imbedded into thew SMART software. Searchable items for utilities and fracture critical details were added to facilitate the rapid location of items that may have been impacted by seismic events. The utility information was not available following the Northridge earthquake preventing Caltrans from being able to quickly identify box girder structures with natural gas, petroleum or high-pressure water lines in them. During future events, the identification of all bridges within the affected area can be quickly identified. Fracture critical and fatigue prone details has been an item that the department has closely tracked for many years but was never available in a searchable format.

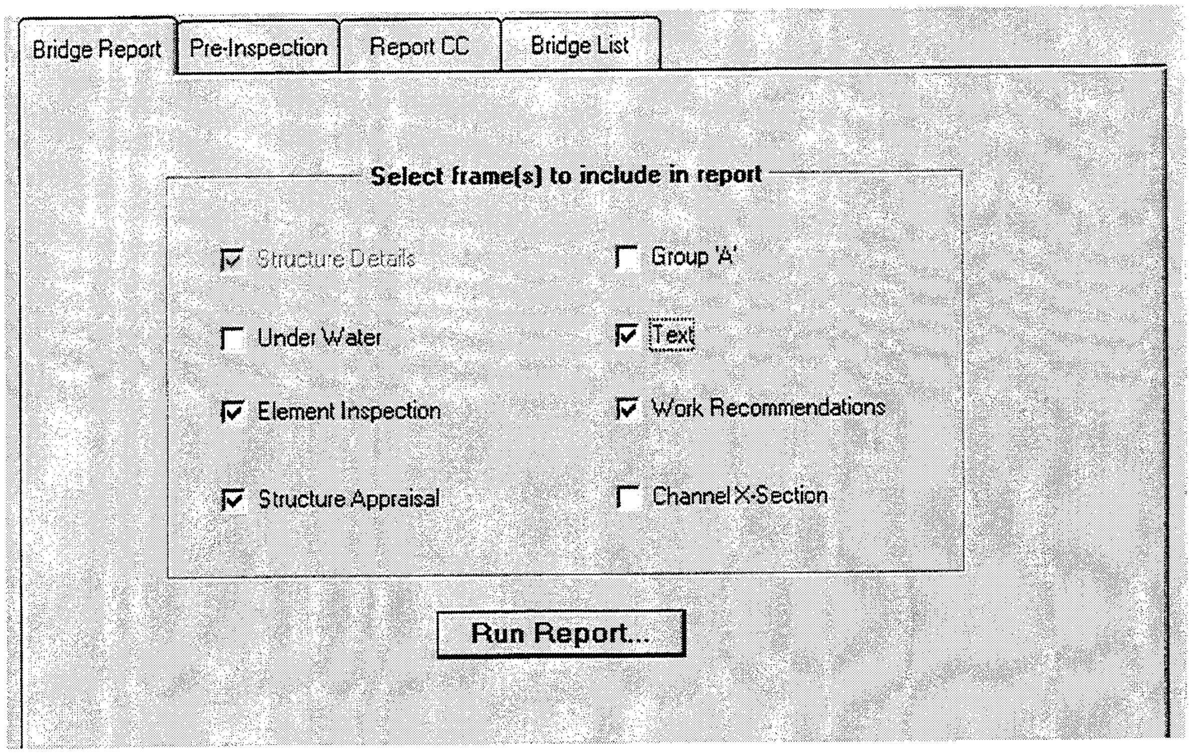
Figure 11 – Fracture Critical and Fatigue Prone Details



Using SMART it is now possible for Caltrans bridge managers to quickly locate all bridges that posses a certain detail or combinations of details. The screen shown above also acts as a collection tool to assess the true cost of performing fracture critical bridge inspections.

Once all the pertinent information has been entered into the database, the SMART system performs all Federal Coding and report generation tasks. The Federal Coding of all bridge inventory items is performed through software coding utilizing pick-list and list of values in the majority of the cases. Figure 8 is a good example of how the inventory data items utilize both English descriptions as well as coded values. To accomplish the goal of automated report generation, the Oracle report generator was used. A single bridge inspection report that consists of many optional pieces was developed. Using this concept it was possible to use a single report format and let the user pick and choose which pieces they wanted to appear in the final report. For example, after the completion of a routine bridge inspection the inspecting engineer can decide if they want to include the channel profile information in the report or not.

Figure 12 – Report Frame Selection Screen



Each checkbox shown in figure 12 represents and optional frame of the final report. The space allocated to unused frames is automatically eliminated creating a clean look in the final report regardless of the actual frames selected. A sample bridge inspection report has been included in the appendix to illustrate the clear look of the generated reports.

CONCLUSIONS AND RECOMMENDATIONS

Through the development of the SMART application we have shown that a well designed software program can eliminate the need for manual Federal Coding of bridge data. We have also shown that a detailed yet flexible bridge reporting format could be developed that can dramatically reduce the time necessary to generate a final bridge inspection report. Using the SMART application it is now possible for bridge engineers in Caltrans to produce final bridge inspection reports in minutes instead of the months it took using the manual process.

Since the original research proposal was submitted, the number of commercially available software programs for bridge inspection continues to increase. One might wonder if custom software development is the way to go or should the agency modify their practices to be in line with an off the shelf program? Should an agency develop their own software or pay to have modifications made to an existing inspection program? The answer to these questions is dependent on the many factors that must be evaluated by each agency. Regardless of the software route taken, the benefits of leveraging modern technology in the bridge inspection process are substantial.

Remote access of bridge inspection information is currently possible using several different approaches. Providing remote access to bridge inspection data and images gives the field engineers the best possible information when making critical decisions. Each of the four methods discussed for remote access has pros and cons. The web approach provides all the necessary functionality with minimal required maintenance. As the communication and data transmission technologies improve, web based software applications will likely dominate all other means of remote access.

A Logical extension of this research might include the incorporation of Geographical Information Systems (GIS) as a means to physically locate bridge sites. GIS offers an additional spatial means of selecting bridge information from a central database.

Other technological advancements such as digital cameras, satellite phones, and voice recognition are providing opportunities to revolutionize the way bridge inspection information is collected, transmitted and stored.

IMPLEMENTATION

The benefits of an automating the bridge inspection data coding and report writing functions were so apparent during the research project that the Office of Structure Maintenance and Investigation funded a parallel implementation and expansion project for SMART. The implementation project trailed the research project by about three months. In a sense the research project was used to explore the technologies available and make a selection for the best approach for Caltrans. Once the equipment and solution approach had been determined the development of that aspect would start under the implementation project. This piggyback implementation approach immediately put the findings of the research into practice.

At the time of this writing (winter 1998) the SMART application has been fully implemented statewide. The application has been expanded from the initial scope to include detailed hydraulic, load rating and project tracking modules. The image viewing capabilities have been perfected and over 60 percent of the approximately 1 million bridge as-built plans and inspection reports have been converted for use from remote sights.

APPENDICES