Tennessee
Department of Transportation
Bridge Inspection
and Repair Office

Evaluation Of Digital Camera Technology For Bridge Inspection

U.S. Department
of Transportation
**Federal Highway
Administration**

Publication No. FHWA-SA-97-100
July 18, 1997

■ Executive Summary

Bridge inspection, performed under the guidance of the **National Bridge Inspection Standards (NBIS),** is the primary means of insuring the safety of the motoring public on Highway Bridges in the United States. When the NBIS standards were first established in 1971, the computer technology available, at that time, severely limited the ability of State Transportation Departments to gather and digitally store bridge information.

However, computer technology has made great strides since the initial establishment of these standards. This has created a desire to improve, automate and expand the amount of bridge information recorded in computer systems. One area that is ripe for digital conversion is the collection of bridge photographic data. Conventional methods of collecting this data, which rely on standard 35 mm cameras, color film, and paper record keeping are costly, laborious and inefficient. Conversion to a process, whereby digital cameras are used to directly capture a photograph into a computer file and where computers and color printers are used to store and print these pictures, has the potential to produce considerable savings in both labor and material costs. However, for these savings to be realized, careful planning and implementation of digital technology is needed.

As part of a cooperative agreement between the Tennessee Department of Transportation and the Federal Highway Administration, a study was conducted to evaluate current levels of digital camera and color printing technology with regard to their application to bridge safety inspection. The results, which are further detailed in this report, generally show that current digital technology is capable of replacing conventional bridge photography methods. Recently introduced digital cameras, such as the Kodak DC-120, are fully capable of capturing bridge inspection photographs in sufficient detail to support a safety and engineering evaluation. Color printing technology, such as that found in color laser and advanced color inkjet printers, is also adequate for the production of color prints. Furthermore, the cost of these systems has fallen to the point that, in many cases, the cost of buying the new equipment and of training inspectors in it’s use, is more than offset by the resulting savings in labor and materials cost. However, each State and/or Government agency needs to evaluate these costs in light of their own particular circumstances.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient''s Catalog Number
FHWA-SA-97-100		

4. Title and Subtitle	5. Report Date
Evaluation of Digital Camera Technology for Bridge Inspection	October 1997
	6. Performing Organization Code
7. Author Terry Leatherwood	8. Performing organization Report
9. Performing Organization Name and Address Tennessee Department of Transportation Fifth and Deaderick Nashville, TN 37243-0349	10. Work Unit No. (TRAIS) 11. Contract or Grant No. **DTFH-71-96-DPO71-TN**
12. Sponsoring Agency name and Address Office of Technology Applications Office of Engineering/Bridge Division Federal Highway Administration	13. Type of Report and Period Code Technical Report 1997 14. Sponsoring Agency Code

15. Supplementary Notes

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Technical Reviewers: John Hooks and Thomas Everett, FHWA; Eriks Jekabson and Brenda Tennessee DOT; Eric Amberge, Kodak; Carole Ann Kirch, National Graphic Supply.

16. Abstract

This document describes the evaluation conducted by Tennessee DOT of a variety of digital cameras for use in documentation of bridge inspections. The results show that current digital technology is capable of replacing conventional bridge photography methods. Recently introduced digital cameras are fully capable of capturing bridge inspection photographs in sufficient detail to support a safety and engineering evaluation.

17. Key Words	18. Distribution Statement
bridge inspection, digital cameras	No restrictions. This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	30	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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■ Introduction

For many years, the responsibility for highway bridge inspection rested mainly with State Governments. However, the disastrous collapse of the Silver Bridge, at Point Pleasant West Virginia, in December 1967, pointed out the need for national standards for bridge inspection. This event helped provide the motivation for the establishment of the ***National Bridge Inspection Standards (NBIS)*** in 1971. These standards mandated the systematic inspection of highway bridges on a maximum two (2) year inspection cycle. The primary goals, of these inspections, were to insure the safety of the structure and to gather the necessary data to calculate the ability of the structure to support vehicular traffic. These standards also established a format for the digital storage, of selected key information, for any bridge that met the twenty feet (6.1 meters) minimum bridge length. Due to the level of computer technology available, this information was limited to a small set of text and numerical fields in a flat database.

Computer technology has dramatically increased in capability since the original establishment of the NBIS Standards. As a result, there is a desire between many bridge engineers and inspectors to take advantage of this expanded technology to increase the speed, capabilities and effectiveness of the Nation's bridge inspection programs. This is accomplished by expanding the amount and type of data that is digitized for computer storage. Most States still limit the amount of bridge data, on their computer systems, to the specific information required by the NBIS Standards. Some States, like Tennessee, have expanded their computerized information to include condition information required for Bridge Management System (BMS) Software such as the AASHTOWARE™ PONTIS computer program. However, a great deal of bridge data only exists as paper records.

For example, the State of Tennessee keeps a report folder for each bridge in the NBIS database. This folder is tabbed into discrete sections and typically contains the following information:

- A map showing the location of the bridge
- A list of recommended maintenance and repair needs
- Mathematical calculations showing the structural capacity of the bridge
- Bridge photographs mounted on letter size paper with text describing the relevance of the image
- A set of report forms that allows the inspector to describe the condition of the individual components of the bridge
- Sketches showing the vertical and horizontal roadway clearance on and under the bridge
- Sketches showing the condition of the superstructure units span by span

- Sketches showing the condition of the substructure units
- Soundings and channel measurements for structures that cross waterways
- Design, repair and “As-Built” plans
- An “Old Report” section which contains the information from the previously performed bridge inspection

Most of the above information exists only as paper records. Paper records present many problems. For example, only one person can physically check out and use the report at any given time. Often an employee who wishes to consult the folder for a particular structure must waste time to locate the current report. The information is unprotected in the sense that, if all the records were destroyed (by a fire, an earthquake, etc.), it would be impossible to replace much of the information. In addition, keeping information in this fashion is extremely labor intensive, wasteful in terms of storage space, and costly. The consumables to maintain this system are high. As one can imagine, the purchase of paper, toner, film and film development services, all add up to an expensive method of operation. The laborious nature of paper methods also creates delays in the transfer of information from the field to the Bridge Headquarters Office. For deteriorated bridges, these delays can act to slow the response of State Bridge Repair Officials in taking action to remedy the situation.

Having bridge information in a digital format could act to address many of the above concerns. By storing information digitally, the amount of consumables and storage space could be reduced, and this would also allow off-site backup of the information. Multiple employees could view the same bridge information, simultaneously, if the system was set up as a multi-user database application. In addition, such a system could speed the transfer of information from field offices and reduce the amount of labor required for report handling by allowing electronic organization and transfer of updated information.

However, movement of this data from a paper format to a computerized format is not a casual undertaking. Most State bridge departments have gathered a massive amount of information over the years. In digital form, it would likely require tens of gigabytes of computer storage. As the current paper methods developed over a period of years, the growth of digital methods will also take time to mature. For most complex problems, success is achieved by breaking down the problem into smaller steps that can be solved individually. Similarly, the deployment of computerized bridge inspections systems can be accomplished by moving individual components to a digital format one at a time.

One area that is ripe for digital conversion is the collection of photographic information. Since the inspection report must be reviewed by structural engineers, who cannot visit every site personally, the documentation of problem areas by means of clear photographs is crucial. Currently these photographs are taken with conventional 35 mm cameras and color film. However, as pointed out previously, the labor and materials cost of using these cameras are high. With new computer technology, it should be possible to capture these photographs in digital form. Of special interest are the recent development and marketing of many new models of digital cameras. Unlike conventional cameras, digital cameras can capture a picture and store it directly as a computer file.

In cooperation with the Federal Highway Administration, the State of Tennessee has undertaken an evaluation of current digital camera technology from the viewpoints of the bridge engineer and bridge inspector. Of special concern was the suitability and cost effectiveness of using digital camera technology as a replacement for conventional 35 mm cameras and standard color film for bridge inspection. This report details the methods used to evaluate these digital cameras and presents our findings and recommendations.

■ Test Methodology

The explosion of digital camera technology, in recent years, has paralleled the rapid expansion of computer and world wide web technology. As a result, there are dozens of digital cameras on the market with new models being introduced continuously. These models range from inexpensive cameras designed for home use, through mid-range models designed for business use, on up to high-end models designed for professional photographers. Clearly, it is neither feasible nor desirable to test every available model on the market for this evaluation. Some criteria were needed to exclude models that have little or no application to bridge inspection. Our preliminary evaluation showed that the mid-range models, designed for business use, would likely prove most suitable for use in bridge inspection activities. Therefore, two (2) requirements were used to narrow the selection of cameras in our evaluation. These requirements were:

1. The camera must be capable of capturing a color image with a resolution of 640 by 480 or better. By necessity, bridge inspection photographs must show problem areas in sufficient detail to allow a structural evaluation of the problem. It was felt that this was the minimum level of resolution that could show this level of detail. In addition, this criterion allowed us to exclude the inexpensive cameras, such as the Kodak DC-20 or Kodak DC-25 models, which are primarily designed for use in the home market. Both of the above models are limited to a maximum resolution of 493 by 373.

2. The camera must cost less than $2000.00. This criterion allowed us to exclude the high-end cameras that are primarily designed for professional photographers. In addition, for conversion to digital technology to be cost effective, the cost of the new equipment must be reasonable.

Using the above criteria, a total of nine (9) digital capture systems were selected for this evaluation. The specific test systems are listed in Table 1. This table summarizes some relevant features of each camera. Specifically, it lists the dimensions of the camera in millimeters, the weight of the camera in grams, zoom capability, minimum focus range (important for close-up shots of cracking, corrosion, etc.), power requirements, and whether the camera can accept additional flash card memory to expand the number of pictures that can be taken before downloading is necessary. Using only the available internal memory, these cameras typically take fifteen (15) to twenty (20) photographs in normal mode and seven (7) to ten (10) photographs in fine (High Resolution) mode before filling the memory. Our inspectors have said that they would prefer a greater storage capacity than the above limits allow. This suggests that the ability to use flash memory cards is a desirable feature. These cards are readily available in the 4 MB to 12 MB sizes and could increase capacity up to 80+ photographs even in fine mode.

TABLE 1

CAMERA	Len x Width x Height (mm)	Weight (g)	Zoom	Min. Range (m)	Power Req.	Flash Card
Chinon ES-3000	150 x 16.5 x 62	520	3X	0.7	4 AA (4)	YES
Camcorder with Snappy Device	64 x 124 x 22	142	16X (1)	N/A (3)	9 Volt	N/A
Epson Photo PC	48 x 164 x 90	312	None (2)	0.6	4 AA (4)	NO (5)
Kodak DC-40	155 x 135 x 56	454	None (2)	1.2	4 AA (4)	NO
Kodak DC-50	152 x 119 x 64	527	3X	0.5	4 AA (4)	YES
Kodak DC-120	146 x 108 x 55	636	3X	0.7	4 AA (4)	YES
Ricoh RDC-1	76 x 142 x 19	256	3X	0.4	Battery Pack	YES
Ricoh RDC-2	76 x 142 x 28	289	1.5X	0.01	4 AA (4)	YES
Sony DKC-ID1	130 x 181 x 67	653	12X	0.8	Battery Pack	YES

NOTES:

1. The snappy device is not a digital camera. Instead, it is a device that can be attached to the parallel port of a desktop or notebook computer. It can accept a video feed from a camcorder or VCR and, using software on the computer, can capture selected still images. In our test, we used the snappy device with a Panasonic camcorder (Model #: PV-IQ315). The camcorder had a 16X zoom capability. The dimensions presented here apply to the snappy device alone. Naturally, the required camcorder unit was much larger.

2. These cameras do not have any built-in zoom capability. However, both can use a standard 37mm lens to add zoom ability.

3. For the snappy device, the minimum focus range depends on the device used to capture the video. Therefore, it is a function of the specific model camcorder selected.

4. These cameras can use standard or rechargeable AA batteries. They can also use an optional AC adapter.

5. The Epson Photo PC camera cannot use standard Flash memory cards. However, additional memory can be added to the camera with proprietary memory units purchased from Epson.

Besides the physical characteristics of the camera, another consideration is its cost. For the purposes of this test, we purchased many of these cameras using our standard competitive bid purchase procedures. The actual pricing for these cameras is volatile, however, and will also vary depending upon the options selected. For example, the purchase of large flash memory cards or optional AC adapters would increase the base cost. For these test units, our base cost is listed in Table 2 below:

TABLE 2

CAMERA	PURCHASE PRICE
Chinon ES-3000	$ 672.00
Camcorder with Snappy Device	$ 748.16
Epson Photo PC	$ 384.17
Kodak DC-40	$ 488.58
Kodak DC-50	$ 708.58
Kodak DC-120 (1)	$ 900.00
Ricoh RDC-1	$ 1,676.75
Ricoh RDC-2 (2)	$ 949.00
Sony DKC-ID1	$ 1,499.58

NOTES:

1. The Kodak DC-120 camera is new. We were able to borrow a pre-production unit from Kodak for testing. According to Kodak, this camera will be priced below the $1,000.00 level. This price is an estimate based upon information obtained from Kodak and from Camera resellers.

2. The Ricoh RDC-2 camera was introduced onto the market after the beginning of this evaluation project. Like the Kodak DC-120 camera, we were able to borrow a test unit. The price listed for this camera is an advertised retail price. Government purchasers of this camera probably can obtain a further discount.

Once we obtained the test units, we distributed the cameras to our bridge inspection teams along with a questionnaire. The questionnaire was designed to measure the performance of the camera based upon the opinion of the field personnel. The inspection teams were asked to return the questionnaire, along with a sample of the resulting picture files, to our Headquarters Office for inclusion in this report.

To gauge the quality of the photographs, the resulting picture files were viewed on several computer systems. The first computer was a Compaq 166 Mhz pentium system with 32 MB of RAM, 2 GB hard disk and a 21 inch monitor. The monitor was configured to run at a resolution of 1024 by 768. Many photographs were also viewed on an IBM 120 Mhz pentium notebook computer with 16 MB of RAM. This computer used a dual scan LCD color panel that was configured to use a resolution of 800 by 600. Finally, some photographs were viewed on a Dell 486 desktop system with a 14 inch monitor configured to run at a resolution of 640 by 480. It was our desire to view the photographs on a range of systems to decide the most appropriate level of computer system for use with a digital photographic system.

There will always be a need to produce hard copy prints of bridge photographs. In a totally digital bridge inspection and evaluation system, hard copy prints would not be needed for most activities. Bridge evaluation could be effected by calling up the required information on a computer monitor. However, even in such a complete system there would still be a need to produce occasional copies for individuals (Attorneys, News Reporters, Historians, etc.) with a legitimate interest in current and past bridge conditions. In the transition period, before complete conversion to digital methods, it is likely that extensive production of color prints will be needed. Therefore, as part of this evaluation, we produced several color prints to evaluate the effectiveness of currently available print systems.

As in the case of the digital cameras, there are many color printer models available. Furthermore, these printers rely on a wide range of technologies to produce color prints. Our criterion, for selecting possible printers, was to try to select printers that provide both reasonable cost and adequate performance. The least expensive color printers are based upon color inkjet technology. Unfortunately, most of these printers are designed for modest home use and are limited in the amount of sustained printing that they can withstand. For example, Hewlett Packard produces several models of color inkjets. Most, however, are only rated, according to their specifications, to produce 160 color prints per month. While this number of prints might be adequate for a totally digital system, it would not be adequate for a transition system where hard copy prints are produced for most bridges. Hewlett Packard does produce an inkjet printer (Model #: HP-1600) designed for business use. This printer is rated to produce a maximum of 12,000 prints per month. This would be more than adequate for a transition system, therefore, we selected a HP-1600 as one of our test printers.

To test how the prints would look on a network level color printer, we also purchased a Xerox 4915+ color laser printer. This allowed us to do a comparison between the laser and inkjet methods of producing color prints. The results of our evaluation, of both camera and print systems, are presented in the next section.

Test Results

In the paragraphs below, each digital capture system is described along with comments by our bridge inspectors. In addition, sample photographs from our test are included in the appendices of this report. Each sheet in Appendix A contains two (2) photographs from the system listed at the top of the sheet. These sheets were all printed on plain paper with the Xerox Color laser printer. By looking through this section, the reader can obtain a direct visual comparison of the quality of output that these systems can create with respect to each other.

During the test period, an incident occurred which gave a practical demonstration of the utility of digital cameras. On May 8, 1997, our Region III Bridge Office received a report that the State Route 7 bridge over the Duck River in Maury County was exhibiting distress. They immediately dispatched a bridge inspection team to examine the structure. The team discovered that severe decay in a timber bent had caused the bent to buckle and move both vertically and horizontally. Because of this movement, two beams in one span had slipped off their supports with a third beam barely retaining its seat. Since the bridge only had a total of five beams, this was an extremely serious condition. Our inspectors immediately closed the bridge to all traffic and informed our Headquarters Office about the situation.

The manager, of our Headquarters Inspection and Repair Office, needed to have the condition visually documented so that an evaluation of the needed level of emergency repairs could be conducted. The author of this report was asked to visit the site and make an evaluation. The bridge was located about forty-one (41) miles (66 km) outside the City of Nashville. Using the Sony DKC-ID1 digital camera, the author photographed the distressed bent, returned to the Headquarters Office, transferred the photographs to his desktop computer and printed them on the Xerox 4915+ color printer. The entire exercise took approximately four hours. By using the digital camera, the author was able to place the needed information into the hands of the Repair Office Manager that same day. These same photographs have also been included in this report. They may be found in Appendix B. If the photographs had been taken with a conventional film camera, the time required for film development would have precluded such a fast production time. If the bridge inspection team had used a digital camera and notebook computer system, they could have transferred the needed information via a modem. In this event, an additional visit to the site by a Headquarters engineer would not have been necessary and the photographs could have been used within an hour of being transmitted.

Chinon ES-3000 Digital Camera - The Chinon camera is a compact, single piece camera that, in design, externally resembles the Kodak DC-50 and DC-120 series. It has many features that are desirable in a field camera, such as (1) zoom capability, (2) Flash card memory expansion, (3) ruggedness and (4) ease of use. However, it is limited to a maximum resolution of 640 by 480 and does not provide a means of previewing the photographs. In comparison to many other cameras, its photographs are fuzzy and unclear. Part of the reason for this may be its lower resolution but other cameras, which also use a lower resolution, produced noticeably better pictures. Our inspectors found the camera easy to use but, because of the quality of the pictures, recommended against using this camera.

Camcorder with Snappy Device - The option of being able to review a video tape, and capture images from it, has great appeal for bridge inspection. The video tape contains thousands of potential images, which makes it easy to get the exact picture to illustrate a problem. When all the features, present in modern camcorders, are combined with a self-contained capture unit, like the Snappy, the potential for application to bridge inspection is great. This is especially true for inspection teams, like those in Tennessee, who have access to a notebook computer in the field. Therefore, the camcorder / Snappy system was included in this evaluation although it is not a digital camera type system.

Unfortunately, this system did not live up to expectations. Operating both camcorder and snappy capture systems makes the capture process unnecessarily complicated. In addition, it is difficult to capture clear images with this device. The best quality shots are obtained by freezing the video tape image and then using the Snappy. We tried this procedure with both the camcorder and with various video cassette recorders (VCR). None of these units could freeze the picture perfectly still. As a result, the captured image always seems to blur. It might be possible to capture high quality images with the Snappy system but it would require both skill and a careful selection of equipment. Because of the extra effort involved, the author cannot recommend the use of a camcorder / Snappy system for bridge inspection purposes.

Epson Photo PC - The Epson camera was the least expensive camera tested. However, this low cost translates into a camera with limited features. It cannot use standard Flash memory cards, it requires an additional lens to add a zoom capability, and, according to our inspectors, needs a better flash unit. In defense of the camera, it took good quality pictures despite being limited to a 640 by 480 resolution. However, our inspectors said that a higher resolution was still occasionally needed. Our conclusion is that it is worth paying more to get the extra features.

Kodak DC-40 - The Kodak DC-40 shares many of the same limitations as the Epson. It operates at a slightly higher resolution (756 x 504) and takes better photographs. It is our understanding that Kodak has decided to phase out the DC-40 camera in favor of more advance models.

Kodak DC-50 - The DC-50 has most of the features needed in an inspection camera. Its weaknesses are a mid-range resolution (756 x 504) and a lack of any means to preview the photographs. However, the reviews from our bridge inspectors were mostly favorable. There is no doubt that the Kodak DC-50 will do an acceptable job in the bridge inspection role.

Kodak DC-120 - The DC-120 is a new camera that, at the time of our evaluation, Kodak had just introduced onto the market. Kodak was kind enough to lend us a pre-production unit to test. It is an excellent camera. Kodak has boosted the resolution of this camera to 1280 by 960. As a result, the camera, when used correctly, can take crystal sharp photographs. In addition, kodak has added the ability to preview photographs and the ability to use an external, detachable flash unit to all of the other features found in the DC-50 series. In design, the unit is a rugged, one piece unit similar to the DC-50. We did have some compatibility problems between the transfer software, which came with the camera, and our IBM Thinkpad™ notebook test computer. However, the software worked fine on our Compaq desktop system. Our conclusion is that the DC-120 has great potential as a bridge inspection camera.

Ricoh RDC-1 - The Ricoh RDC-1 was the most expensive camera tested. Part of the reason is that the RDC-1 is a “gadget” camera. The camera is built up out of a set of modules each of which may be purchased separately. The resulting camera takes good quality pictures but is extremely delicate in design. Our inspectors had serious doubts about the ability of the RDC-1 to stand up to hard field use. In addition, the modular nature of the camera makes it complicated to use. The RDC-1 camera is clearly designed for use by a “Camera hobbyist” rather than as a serious work tool.

Ricoh RDC-2 - Ricoh must have received some comments about the fact that one had to buy many extra components, to properly use the RDC-1, because they designed the RDC-2 to be less modular. The RDC-2 box says that everything needed (including batteries) to start taking photographs was inside. This certainly was not true with the RDC-1. The RDC-2 camera is much less expensive than the RDC-1. It seems to take slightly fuzzy photographs, when compared to the RDC-1, although it uses the same resolution. Like the RDC-1, but unlike most other cameras, it has the ability to capture a few seconds of sound recording along with a photograph. This means that a bridge inspector might record a brief comment with each picture. However, Ricoh reduced the zoom capability to only 1.5x instead of the 3x zoom used in the RDC-1. Although the RDC-2 camera could be used for bridge inspection, more suitable cameras are available.

Sony DKC-ID1 - The Sony is a good camera. It has most of the features that are needed in a serious work camera. It works at a lower resolution (768 x 576) than the Kodak DC-120 and, as a result, cannot quite match the Kodak in picture quality. Nonetheless, the Sony pictures are acceptable for most purposes. One especially desirable feature of the Sony is its 12x zoom lens. This allows a bridge inspector to zoom in to capture good pictures even if the target is difficult to reach because of the height of the bridge. The Sony also comes with a rechargeable battery pack that negates the need to use AA batteries, is quite rugged, and is simple to use. It is more expensive than most cameras, but the extra cost buys some good features. The Sony camera is an acceptable alternative for use in bridge inspection.

Hewlett Packard HP-1600 Inkjet Printer - While the prints produced by the HP-1600 are acceptable for general shots of a bridge, the HP-1600 lacks the ability to print fine details. The HP-1600 is limited to a 300 dpi resolution which is simply too low to show the detail needed for close up shots of problem areas. Using glossy inkjet paper seems to produce only a marginal improvement in quality. Therefore, we cannot recommend the HP-1600 as a suitable printer to produce hardcopies of digital photographs.

Xerox 4915+ Color Laser Printer - The Xerox produced prints that were clearly superior to the HP-1600. This results from the fact that the laser method of printing is better than most inkjet methods for producing detailed photographs on plain paper. The Xerox operates at a resolution of 1200 by 300 dpi which, in effect, allowed it to put four times more information onto the printout. The drawback of using color laser printers, however, is their high cost. The Xerox is at least twice as expensive as the HP-1600 despite being considered a relatively inexpensive model of color laser printer. Generally, the cost of a color laser unit can only be justified by a high volume of printing.

■ Conclusions and Recommendations

The results, from this study, clearly show that the technology does exist to replace conventional 35 mm cameras with digital cameras for the purposes of bridge inspection. In general, the following conclusions and recommendations can be drawn from this study:

- The best all round camera for bridge inspection, of those that were evaluated, was the new Kodak DC-120. It has a one piece design, 3x zoom capability, expandable memory storage, high resolution, photo preview features and the ability to work with an external flash unit. This allows the camera to be used for a broad range of pictures such as (1) photos taken under a bridge in dim light, (2) sharp close-ups and (3) general shots of the structure. In addition, the DC-120 has a reasonable price of under $1,000.00 per unit.

- The Kodak DC-50 was the least expensive camera that was deemed acceptable for use in bridge inspection. It generally sells for two to three hundred dollars less than the DC-120 but this savings means using a less capable camera.

- If a powerful zoom capability is needed, then the Sony DKC-ID1 camera is a good choice. The tradeoff for choosing the Sony, however, is a lower picture resolution (compared to the DC-120) and a much higher price tag.

- In general, none of these cameras are perfect for bridge inspection. The ideal camera would combine the resolution, external flash and other features of the Kodak DC-120 with the 12x zoom capability of the Sony DKC-ID1. The camera would also include some means to mark the resulting picture files with identification information about the bridge. How this could be done is not clear but using a sound clip, like the Ricoh cameras, might be feasible. In addition, the ideal camera would be more rugged and waterproof than most commercial models of digital cameras. Finally, the ideal camera would be easy to use and would pack all these features into a camera that would sell for a reasonable price. No single camera tested could match all these points but some came close.

- Almost all of these cameras are designed to operate in a temperature range of 32° degrees to 104° degrees Fahrenheit (0° degrees to 40° degrees Celsius). Therefore, these cameras are not a good choice for use in freezing weather. Since Tennessee is a southern State, this does not impose a significant impediment to using these cameras for bridge inspection here. However, a northern State, which of the necessity must conduct bridge inspections in sub-freezing weather, may find this to be a problem.

- Most of these cameras come with software that can convert and save the resulting picture into many file formats. The Kodak cameras save pictures in a proprietary format but the included software can convert it to standard formats. Some of these file formats (BMP, TIF, etc.) employ little or no compression of the picture data. As a result, the picture files are large. Consequently a compressed format, such as the JPEG format, is the best type to use for general storage. Because the JPEG format employs aggressive compression, it produces dramatically smaller files. For example, a DC-120 picture, taken at the 1280 by 960 resolution setting, takes about 3.6 MB of hard disk space when saved in the BMP format. This file stored in the JPEG format will be about 200 KB. In other words, it is about eighteen (18) times smaller. This is a significant factor to consider when one realizes that Tennessee bridge inspectors may take up to 100,000 photographs each year. This large number of photographs also points to the need to develop a database system that can (1) relate the photographs to the identification number of the bridge to which it belongs, (2) relate the photographs to whatever text information the bridge inspector wishes to include for descriptive purposes, (3) relate the photograph to the date that it was taken and (4) print these same aforesaid photographs, text notes and dates (in an organized report style) to a color printer. The Kodak DC-120 came with a software database designed to store pictures but we had a very limited time in which to evaluate it. More development work in this area is clearly indicated.

- Saving photographs as digital information introduces the ability to use software to enhance the resulting picture. For example, if one takes a photograph with a conventional 35 mm camera, and it turns out dark, then not much can be done. However, a dark digital camera photograph can be adjusted, using imaging software, to compensate for this defect. However, this ability to adjust photographs also introduces problems. Since bridge inspection reports are legal documents, and may even be used in criminal or civil actions, the legal ramifications, of altering a photograph, need to be considered. How does one insure that digital data has not been tampered with, after the fact, to hide wrongdoing? Any State that moves it's bridge inspection data, to a digital format, needs to consider what, if any, legal problems may result.

- All of these cameras used a considerable amount of power, especially when downloading photographs to a computer, under field conditions. If a Bridge Inspector uses conventional AA batteries to power the camera, he may find, as our inspectors did, that battery life is short. Using an AC adapter and/or a rechargeable battery / power pack combination is required if one wished to keep costs down.

- Producing acceptable hardcopy color prints continues to be a problem when working with digital photographs. If printing can be centralized so as to produce a large volume of work (> 5000 prints per month), it will be cost effective to use a networked color laser printer and/or Copier. In Tennessee, this may be possible at some of our main Regional Bridge Inspection Offices. However, most of our small local Bridge Inspection Offices would produce a smaller volume of just 500 to 1,500 prints per month. It would be difficult to justify the high cost of a color laser printer for these locations. It was thought that the less expensive HP-1600 printer could be used for these local offices but it does not produce acceptable quality output. It is possible that inkjet technology from another manufacturer might be acceptable. For example, Epson produces an inexpensive business inkjet printer, the Epson Stylus Color 800, which (according the specifications listed by Epson) can produce 720 dpi color output on plain paper. This is much better than the 300 dpi resolution produced by the HP-1600 and should be acceptable for most uses. Epson achieves this level of output by using piezo inkjet technology rather than conventional inkjet technology. Epson does not list the rated output of this printer on a per month basis but they do list a total lifetime print volume of 75,000 pages. Given a normal printer lifespan, this should be adequate for a small office. In addition to being an order of magnitude cheaper than a color laser, the cost of consumables, for this printer, also seems to be reasonable. Finally the printer is listed as printing up to seven (7) pages per minute in color. Generally, we have found that these print speeds are very optimistic when printing color photographs. For example, the Xerox 4915+ is said to print color sheets at up to three (3) pages per minute. However, its average speed with our photographs was 3.8 ***minutes per page***. This is more than an order of magnitude slower than its rated speed. Nonetheless, the Epson would probably prove fast enough for the lower volume printing that a local inspection office would need. Unfortunately, we were not able to test the Epson for this study but, based on the published specifications, this printer may have an application to this problem.

- We found that working with large picture files was computer intensive. Therefore, we recommend that fast pentium (>166 Mhz) computer systems with 32 MB or more of RAM be made available to the bridge inspectors who manipulate and print these files. In addition, we found that using a large monitor, which is set for a high resolution, allowed each picture to be displayed to its best advantage. In our test, the same picture files looked noticeably better on the 21 inch screen of the Compaq desktop when compared to the 14 inch screen of the Dell desktop computer. For the employee who must work with digital camera photographs on a daily basis, a 17 inch to 21 inch monitor powered by a high resolution graphics card is therefore recommended.

- Although most of these cameras can take pictures at reduced resolutions, the most acceptable photographs result only from the highest resolution possible. Because of the safety aspects of bridge inspection, the most detailed photographs obtainable are needed to document damage or deterioration. However, wide angle photographs, which are taken only to document the general setting of the structure, may acceptably use a lower (Normal) resolution mode. Setting the cameras to their highest possible quality exacts a cost. The resulting image files are large. Therefore, storage of these files must be an important consideration. To reduce file size, the normal mode should be used when fine detail is not required. The desktop or notebook computers, used for storing and printing these files, need to be equipped with fast and large hard drives. Even the multi-gigabyte hard drives that are common today will fill up rapidly when large numbers of image files are saved to them. In addition, the memory of the camera needs to be considered. Most cameras come with one or two MB's of internal memory but this is quickly consumed when the camera is set to its highest resolution. Therefore, expanding the camera's memory with flash memory cards is necessary. Probably the least expensive system that would be acceptable would be a Kodak DC-50 equipped with a 4 MB Flash memory card. However, a much better system would be a Kodak DC-120 equipped with an 8 MB to 12 MB flash memory card. When considering the purchase of a digital camera unit, the cost of extra components (such as flash memory cards, AC adapters and external flash units) needs to be included.

- The questionnaire results generally show that our bridge inspectors found digital cameras easy to use. However, there are enough differences between digital cameras and conventional cameras to indicate a need for familiarization training. In addition, imaging software and color printing introduces additional complexities. States moving to digital camera technology need to arrange to provide the necessary amount of training to their Bridge Inspectors and/or Office Personnel. It may be possible that the manufacturer of the camera (Kodak, Sony, etc.) may be helpful in this regard.

In summary, the impressive advancements in digital camera technology and color printing have created the promise of both improved productivity and reduced cost for State Bridge Inspection Departments. However, these results proceed only from (1) a careful selection of equipment, (2) careful selection and/or development of software, (3) training and (4) improved business practices. Selecting and implementing new technology requires both knowledge and planning. If this report has helped disseminate some information needed in this area, then the goals of the author, the State of Tennessee and the Federal Highway Administration have been met.

■ APPENDIX A

FIELD TEST PHOTOGRAPHS

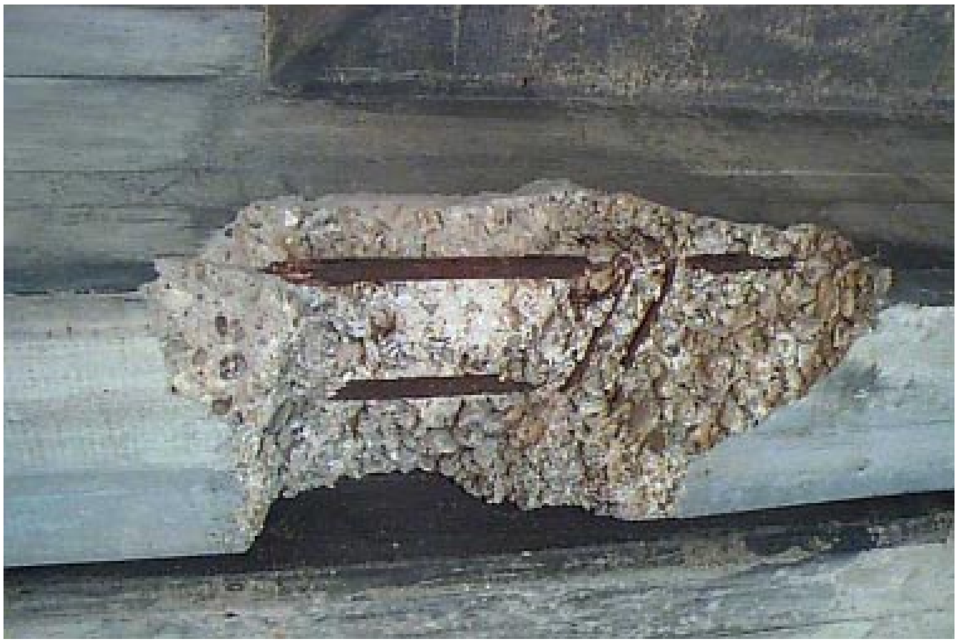
CAPTURE SYSTEM: KODAK DC-40 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION 756 x 504 x 16,777,216

LOWER CHORD OF STEEL TRUSS

CONCRETE BRIDGE ABUTMENT

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: KODAK DC-50 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 756 x 504 x 16,777,216



CONCRETE T-BEAM WITH COLLISION DAMAGE

ELEVATION VIEW OF ROADWAY UNDERPASS

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: KODAK DC-120 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 1280 x 960 x 16,777,216

ENDPOST AND BEARING OF STEEL TRUSS

UNDERSIDE OF TRUSS BRIDGE

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: RICOH RDC-1 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 768 x 576 x 16,777,216

CONCRETE BRIDGE PIER

DRIFT AT BRIDGE PIER

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: RICOH RDC-2 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 768 x 576 x 16,777,216

TIMBER BRIDGE PILE WITH DECAY

UNDERSIDE OF STEEL BEAM SPAN

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: SONY DKC-ID1 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 768 x 576 x 16,777,216

ROADWAY APPROACH TO STEEL TRUSS BRIDGE

STEEL TRUSS CONNECTION

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: CAMCORDER WITH SNAPPY VIDEO CAPTURE
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 640 x 480 x 16,777,216

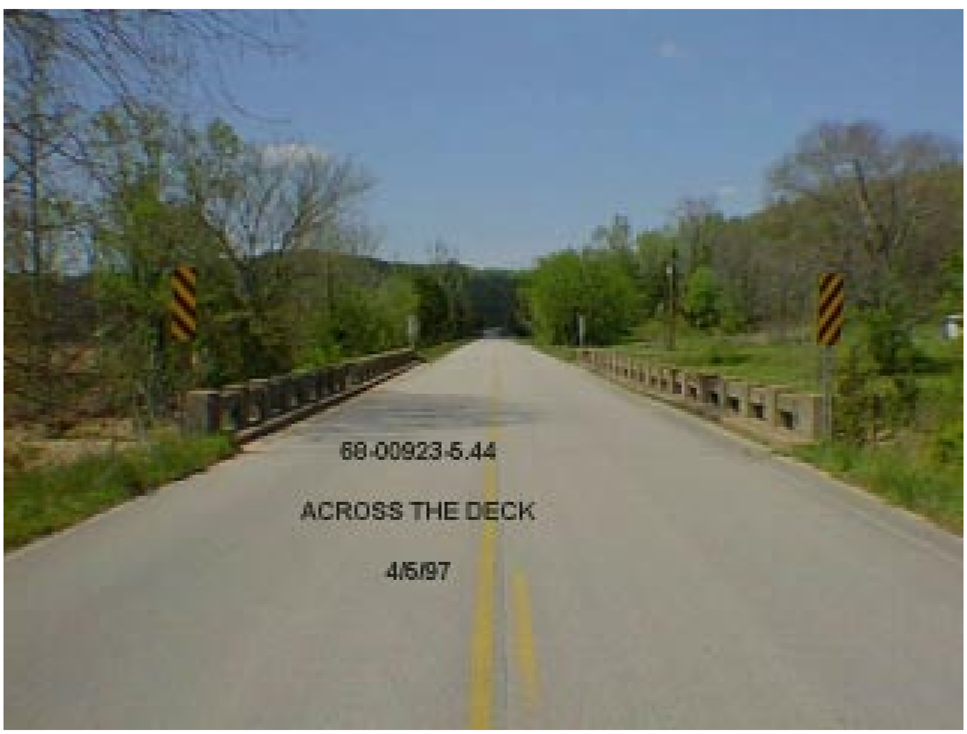
CONCRETE SPALL IN BRIDGE DECK

UNDERSIDE OF BRIDGE DECK

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: EPSON PHOTO-PC DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 640 x 480 x 16,777,216

END OF BENT CAP



VIEW ACROSS BRIDGE DECK

FIELD TEST PHOTOGRAPHS

CAPTURE SYSTEM: CHINON ES-3000 DIGITAL CAMERA
PRINT SYSTEM: XEROX 4915+ COLOR LASER PRINTER
TYPE OF PAPER: PLAIN PAPER
RESOLUTION: 640 x 480 x 16,777,216

PATCHED AREA IN CONCRETE DECK

CONCRETE BRIDGE RAIL AND METAL POST

■ APPENDIX B

BRIDGE INSPECTION PHOTOGRAPHS

BRIDGE NO: 60 - SR 7 - 15.69 over the Duck River
DATE: May 8, 1997
CAMERA: SONY DKC-ID1 (768 x 576 x 16,777,216)

LOSS OF BEARING ON CAPBEAM - EXTERIOR BEAM "A"

LOSS OF BEARING FOR FIRST INTERIOR BEAM "B"

BRIDGE INSPECTION PHOTOGRAPHS

BRIDGE NO: 60 - SR 7 - 15.69 over the Duck River
DATE: May 8, 1997
CAMERA: SONY DKC-ID1 (768 x 576 x 16,777,216)

CAPBEAM MOVEMENT AT BENT #8

SEVERE DECAY IN EXTERIOR TIMBER PILE "A"

BRIDGE INSPECTION PHOTOGRAPHS

BRIDGE NO: 60 - SR 7 - 15.69 over the Duck River
DATE: May 8, 1997
CAMERA: SONY DKC-ID1 (768 x 576 x 16,777,216)

SEVERE DECAY IN INTERIOR TIMBER PILE "B"

UNDERSIDE OF BRIDGE DECK AND TIMBER CAPBEAM

BRIDGE INSPECTION PHOTOGRAPHS

BRIDGE NO: 60 - SR 7 - 15.69 over the Duck River
DATE: May 8, 1997
CAMERA: SONY DKC-ID1 (768 x 576 x 16,777,216)

DIFFERENTIAL MOVEMENT OF CURB AND BRIDGE RAILING