HISTORICAL WARRANTY REPAIR COST AS A MEASURE OF LONG-TERM ROOF SYSTEM PERFORMANCE

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This paper uses information from the roofing warranty database of a major roof system manufacturer to compare the relative performance of different roof systems and components over time. In order to provide an economic measure of roof performance, the paper develops a working definition of roof performance to be actual repair expense per unit of surface area for a specified period of time. Using this working definition, the paper provides comparative performance data for both EPDM and modified bitumen roof systems, as well as an analysis of the critical performance components of these systems. The paper also provides comparative performance information regarding the use of EPDM roof systems in reroofing applications involving either the tear-off or re-cover of the existing roof.

KEYWORDS

EPDM, historical repair cost, modified bitumen, relative roof performance, roof repair database.

INTRODUCTION

Beginning with the First International Roofing Symposium in 1977, numerous field studies have been presented regarding the long-term performance of roof systems. These field evaluations have provided many important insights regarding roof performance; however, many of the studies utilized sampling techniques with limited statistical significance. In many cases, the data have been taken from a relatively small sample of roofs, making it difficult to draw statistical inferences to the total roof population. More extensive field surveys, such as NRCA's *Project Pinpoint Analysis*,[1,2] have successfully obtained information from a much larger population of roofs, but this type of study also presents sampling problems. Because the survey relies on the accumulation of voluntary and anecdotal field reports, and because these field reports focus almost exclusively on problem roofs, it is difficult to relate the survey data effectively to the overall population of roofs in service.

Beyond addressing statistical concerns, an effective study of roof system performance also must provide some definition of what is meant by performance. In most cases, previous studies have identified specific roof deficiencies and reported the incidence of these deficiencies among the roofs surveyed. Although this technique certainly has helped to identify a number of important performance issues affecting modern roof systems, several important aspects of roof performance are not addressed. A simple cataloging of roofing deficiencies provides little information about the long-term consequences of each deficiency. How much does the deficiency reduce the service life of the roof? Is effective repair possible? If repair is possible, what is the cost? If repair is not possible, what is the cost for replacement? To provide utility to a definition of roof performance, the economics of roof repair must be considered.

The warranty databases and warranty service records of roofing manufacturers offer an interesting opportunity to expand the roofing industry's understanding of roof system performance. Because these databases are very large, in some aspects, an analysis of the information contained in their records may be more reliable than information gathered from limited or anecdotal sources. Because these service records cover a pre-established population of roofs, it is possible to identify the comparative frequency of different observations within the roof population. Because warranty service records also can identify exactly when a roof was installed and exactly when repairs were performed, it is possible to develop a detailed chronology of roof performance. Finally, because warranty service records document the actual cost of roof repairs, roof performance can be quantified economically. In summary, manufacturers' service records offer an opportunity to compare the relative repair cost of roof systems over time.

Although the service records of roof system manufacturers can provide very useful comparative information with reasonable consistency within the database, it is important to identify the limitations of such records. Because these service records identify the time and the magnitude of repairs that are necessary under the terms and conditions of the manufacturer's warranty, very little information regarding nonwarranted roof repairs can be obtained. For example, costs associated with abuse, interior damages, business interruption, etc., would not be addressed by most manufacturers' service records. In addition, because these records typically cover only the specified warranty period (typically, 10 years), very little information can be obtained concerning the performance of the roofs in the database beyond this warranty period.

As an additional limitation, the warranty service records of roofing manufacturers contain information usually considered to be proprietary, especially the actual unit costs associated with warranty repairs. However, disclosure of proprietary financial information can be avoided by using indexing techniques. Although the specific unit cost spent to maintain a particular segment of warranted roofs is not disclosed, indexing can provide valuable information regarding both historical performance trends and the comparative performance of different population segments.

THE ROOF SERVICE DATABASE

The database used in this study is significant both in size and in scope. In terms of size, the database covers more than more than 200 million m² (2 billion square feet) of roofs installed from 1982 to the present. With an average roof size of approximately 2,000 m² (20,000 square feet), information is available for more than 100,000 roofs installed throughout the United States and Canada during this period. The largest segment of roofs in the database is composed of EPDM systems, with records going back to 1982. The remaining portion of the database consists of modified bitumen roof systems, with records going back to 1987.

Regarding the scope of detail provided in the database, the data record for each roof contains extensive information about the roof design, including:

- construction type
  - new construction
  - reroof with tear-off
  - reroof/re-cover
- system type
  - EPDM—ballasted
  - EPDM—fully adhered
  - EPDM—mechanically attached
  - modified bitumen—APP
  - modified bitumen—SBS
- geographic location
  - city
  - state or province
  - zip or postal code
  - installing contractor
  - contractor name and location
  - current licensing status with manufacturer (active/inactive)
- warranty information
  - date completed
  - date inspected
  - date approved for warranty
  - warranty term in years

Because all of the roofs received a material and workmanship warranty, the database also contains detailed information regarding the timing, cost, and type of repair service performed by the manufacturer during the warranty period. The typical warranty period of almost all of the roofs in the database is 10 years, and the service records for each roof in the database identify the cost and date of all repair expenditures made by the manufacturer during this period. In addition, each repair activity is coded based on the principal roof system component (e.g., field seams and perimeter attachments) that required the repair, allowing for a detailed analysis of the causes of repair costs.

Given the scope of detail available in the database, a number of trends can be analyzed, including the relative performance of roofs over time, the average frequency and timing of repair activities, and the comparative performance of different roof systems, components and construction types.

Some limitations of the database must also be identified. Although detailed repair cost records have been maintained for every roof in the database, these cost records cover only those expenses actually paid by the roof system manufacturer to repair leaks. Accordingly, costs not covered by the manufacturer's warranty are not included in these records. Examples of such nonwarranted repair costs include: 1) the repair of sealants at sheet metal flashings, roof penetrations and mechanical units, 2) repairs caused by severe windstorms, vandalism, or excessive roof traffic, and 3) repairs related to failures in the roof deck, walls, or other substrates. The database also does not record costs for possible consequential damages, such as interior damage or business interruption. Because the license agreement between the manufacturer and the installing applicator requires the applicator to be responsible for workmanship deficiencies during the first two years of service, the recorded repair costs for these two service years obviously will be understated. Although these exceptions must be addressed whenever observations from this study are extrapolated beyond the original data, all of these exclusions have been applied uniformly to the data, allowing for a high degree of internal consistency.

One final issue regarding the database is the efficacy of the repairs made to the roofs. Do the manufacturer's procedures provide a long-term solution for leaks that may occur in the system or do the repairs merely serve as a Band-Aid? One way to respond to this question is to analyze the annual repair cost trend for roofs in the population as they approach the end of their nominal warranty coverage. If the repair cost trend is decreasing each year, it is likely that the repairs that were made previously are providing a reasonably effective solution. However, if the cost trend for the roofs begins to escalate in the later years of the warranty, it is likely that significant additional repairs may be required in order to ensure longer-term roof performance.

METHODOLOGY

- Historical repair cost is defined as the manufacturer's actual recorded spending during a specified period of service. For this study, repair costs are expressed as actual spending during each year of roof service following the initial installation.
- Maintenance costs for any given segment of the database are divided by the total installed surface area of that segment, in order to allow for comparison between different segments of the database. As an example, the annual repair costs per square meter of roofs installed in 1986 can be compared to the same unit costs for roofs installed in 1988.
- In order to adjust for inflation, spending is stated in constant units, using 1982 as base year and adjusting each year based on the U.S. Consumer Price Index for urban areas (CPI-U) as calculated by the United States Bureau Of Labor Statistics. For future projections offered in the study, a constant 2 percent inflation rate is assumed for all years beyond 1996.
- In order to maintain the confidentiality of the actual dollar costs in the database, repair costs are indexed against a baseline year.

EPDM ROOF SYSTEM PERFORMANCE: HISTORICAL TRENDS

Overall EPDM Maintenance Cost Trends

At least five years of actual historical repair costs are now available for all roofs in the database that were installed in

1991 or earlier; these five-year repair costs can be used to measure relative performance. Chart 1 illustrates the overall change in repair spending during the first five years of service for EPDM roofs installed each year from 1982 to 1991, using 1987 as an index year. As illustrated by the chart, unit repair costs for EPDM roofs have declined 92 percent from 1982 to 1991. The most significant period of cost reduction occurs between 1984 and 1987. As will be discussed later in this paper, the large drop in costs from 1984 to 1987 is most likely due to several changes in product technology introduced during those years. Although the improvement trend begins to flatten out from 1987 through 1991, incremental reductions in unit repair costs continue to occur each year, and these incremental improvements account for a total 48 percent reduction in cost even during this relatively flat period. This slow but steady improvement in repair costs in recent years appears to be related to steady improvements in applicator workmanship, most likely a result of increasing skill and commitment on the part of the licensed contractors responsible for installing the roofs.

Timing and Distribution of Repair Costs

In addition to comparisons of cumulative costs, the performance data can be arranged to plot the timing and magnitude of these costs over the service life of various population segments. Charts 2A through 2H provide plots of the ten-year annual repair costs service for EPDM roofs installed each year from 1982 to 1991, using 1987 as an index year. For roofs installed in 1986 or earlier, repair costs for all ten years are taken from recorded cost data. For roofs installed between 1987 and 1991, costs have been projected for the final years of service based on the overall slope and trend of the performance curve for preceding years of service. Each of these individual performance curves are then combined in Chart 2I, providing an overall comparison.

Although the service plots for roofs installed in 1988 or later show a relatively flat curve with a single peak, the plots for roofs installed prior to 1988 have higher slopes and two distinct cost peaks. The presence of two distinct peaks in a distribution curve typically indicates the presence of two separate performance variables. Based on a detailed analysis of individual service records, it appears that the two perfor-

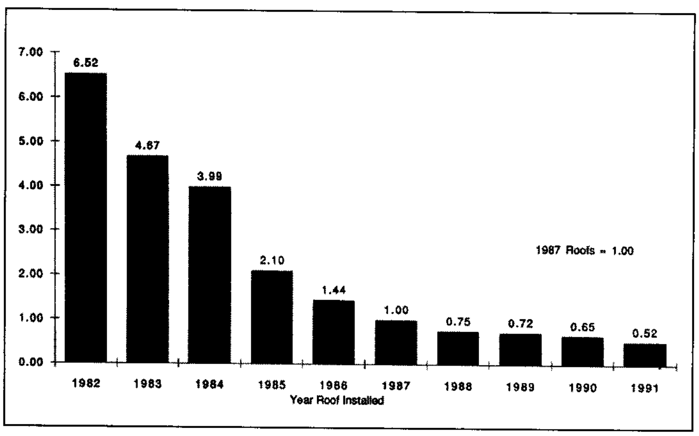

Chart 1: EPDM roof repair costs: First five years of service (indexed cost per square meter).

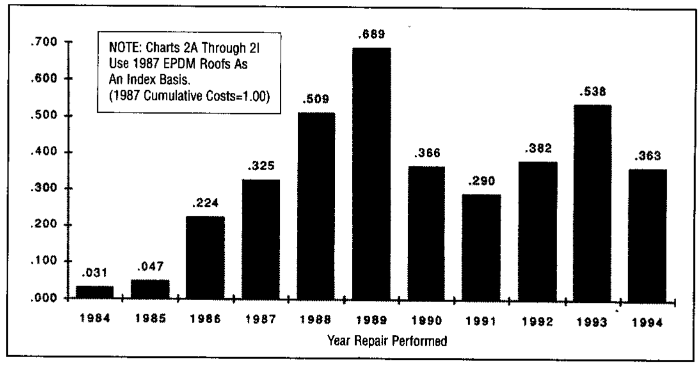

Chart 2A: Repair costs by service year: 1984 EPDM roofs (indexed cost per square meter).

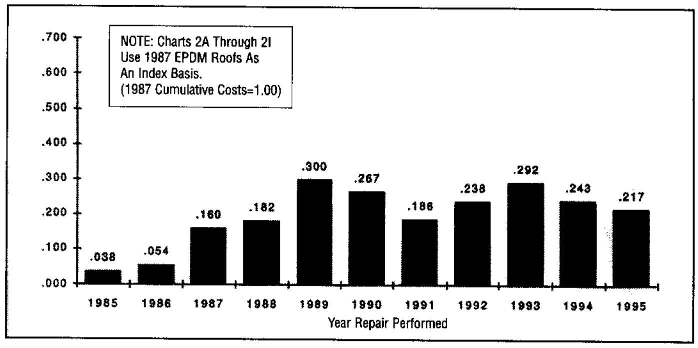

Chart 2B: Repair costs by service year: 1985 EPDM roofs (indexed cost per square meter).

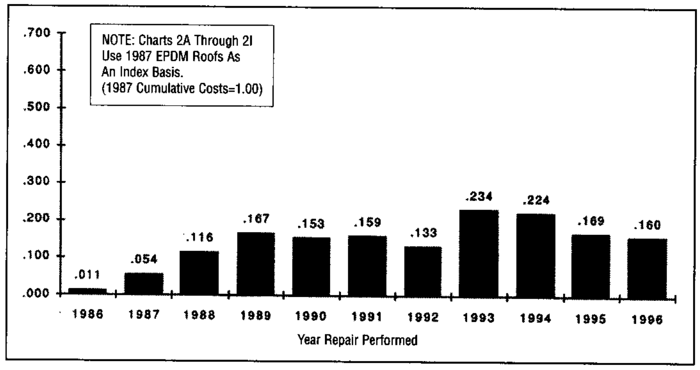

Chart 2C: Repair costs by service year: 1986 EPDM roofs (indexed cost per square meter).

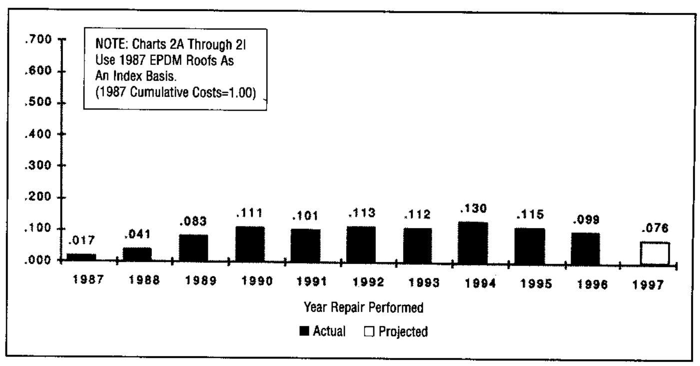

Chart 2D: Repair costs by service year: 1987 EPDM roofs (indexed cost per square meter).

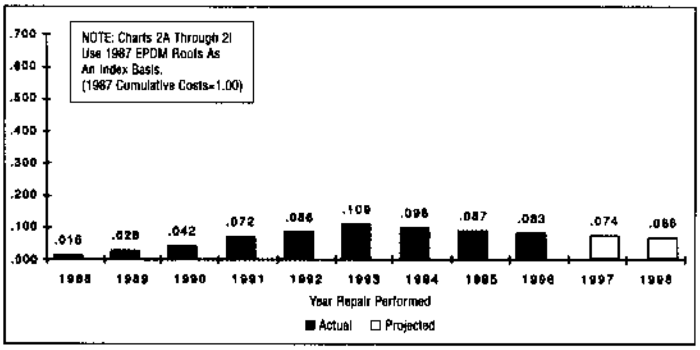

Chart 2E: Repair costs by service year: 1988 EPDM roofs (indexed cost per square meter).

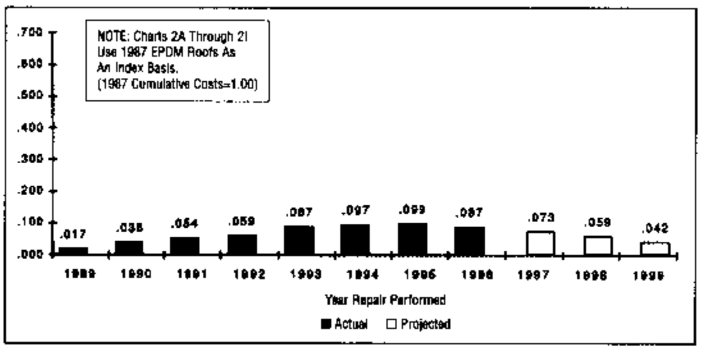

Chart 2F: Repair costs by service year: 1989 EPDM roofs (indexed cost per square meter).

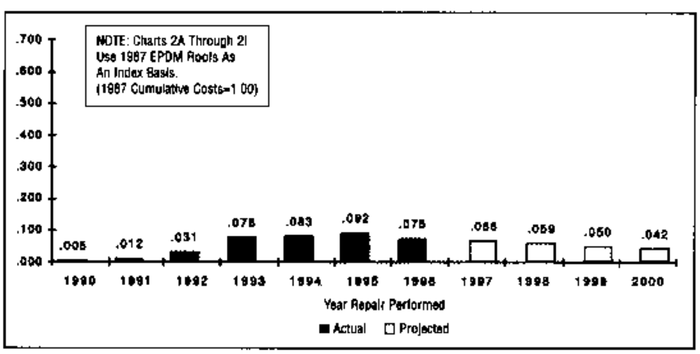

Chart 2G: Repair costs by service year: 1990 EPDM roofs (indexed cost per square meter).

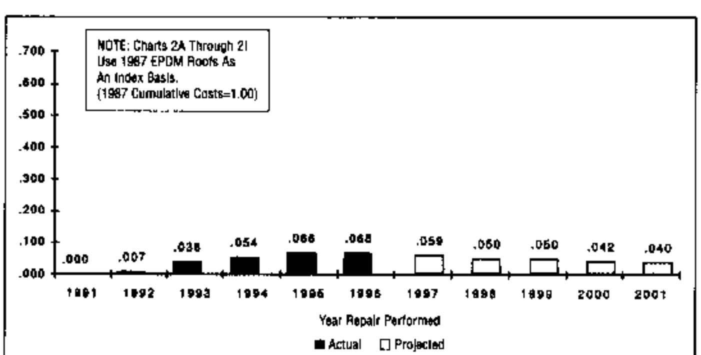

Chart 2H: Repair costs by service year: 1991 EPDM roofs (indexed cost per square meter).

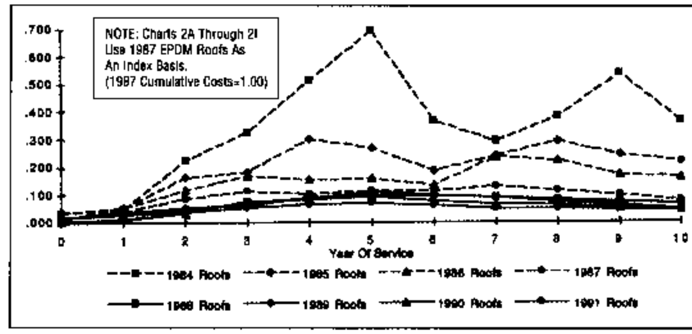

Chart 2I: Actual/projected repair costs by service year: 1984-1991 EPDM roofs (indexed cost per square meter).

mance variables are applicator workmanship and component technology. For all roof years studied, there is an obvious trend for repair costs to increase for a number of years following installation; this trend appears to be caused by workmanship or component deficiencies associated with the original installation of the roof. As will be discussed later in this paper, these deficiencies relate primarily to field seams and perimeter attachments. In either case, these deficiencies appear to increase for a period of time until repairs are made. After repairs are completed, repair costs appear to flatten out or turn downward for the remainder of the ten-year service period. The presence of the second peak in repair costs in the early roof years appears to be associated mostly with the design and composition of specific roofing components that appear to have required repair even after workmanship deficiencies were addressed. Examples of these components are the neoprene-based splice adhesives, neoprene wall flashings, and wood perimeter nailers used frequently in the early 1980s and later replaced with improved technologies.

Repair Costs by Component

Chart 3 provides a breakdown of actual five-year costs by the type of component requiring repair. For this study, these components are divided into three major categories:

- field seams
- perimeter flashings (including base tie-ins, edge metal flashings, and terminations)
- other (primarily curbs, penetrations, and membrane cuts and punctures)

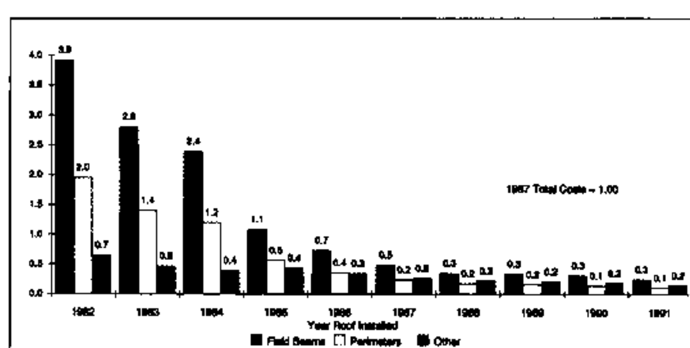

Chart 3: EPDM repair costs by component: First five years of service (indexed cost per square meter).

During the period from 1982 to 1991, repair costs for both field seams and perimeter flashings improved significantly. The trends in this chart appear to reinforce the hypothesis that much of the improvement in EPDM system performance is due to technological changes in seaming and attachment technology. Costs associated with the repair of field seams and perimeter flashings declined 92 percent and 95 percent, respectively, with the most significant improvement occurring between 1985 and 1988. This improvement coincided with the introduction of several important component technologies by the roofing manufacturer:

Year Introduced:	*Technology:*
1985-1986	Butyl-based splice adhesive replaces Neoprene-based adhesive.
1985-1986	EPDM-based wall flashings replace Neoprene-based flashings.
1987-1988	Tape laminates replace conventional metal edge flashings.
1988-1989	Metal battens and screw fasteners replace wood nailers and nails.

Although the improvement in EPDM field seam performance has been generally recognized in the roofing industry, the improvement in the performance of perimeter attachments has not been as broadly acknowledged. Although the data in this study indicates a significant improvement in EPDM base tie-in performance, recent industry articles indicate ongoing concerns. As an example, in its cover letter attached to the May 1996 NRCA special report *EPDM Membrane Shrinkage*,[3] the NRCA Technical Operations Committee stated that it had ".... noticed a dramatic increase in inquiries from members about EPDM roofs that are experiencing a shrinkage problem." At least for the roofs in this manufacturer's database, it would appear that any recent increase in reports of perimeter attachment deficiencies is most likely a function of the overall size of the population of early EPDM roofs rather than an indication of continuing problems with the manufacturer's attachment components or design. In fact, based on the improved performance trends for this manufacturer's EPDM roofs installed in the late '80s and early '90s, it would be reasonable to assume that problems related to the EPDM perimeter attachments covered in this particular roof population will decline in coming years. However, the repair costs for roofs within the early years of this database also clearly indicate that reports of field problems with base attachments will likely increase for any EPDM roofs that continue to be installed using inappropriate designs or inadequate fastening methods.

Repair Costs by System Type

Chart 4 provides a breakdown of actual five-year costs by the basic design of the EPDM roof system. For this study, these systems are divided into three major categories:

- ballasted
- fully adhered
- mechanically attached (includes a variety of systems and attachment methods)

This chart clearly illustrates that the relative performance of these three basic system types has also changed significantly over time. Although both mechanically attached and fully adhered roofs underperformed ballasted roofs in the

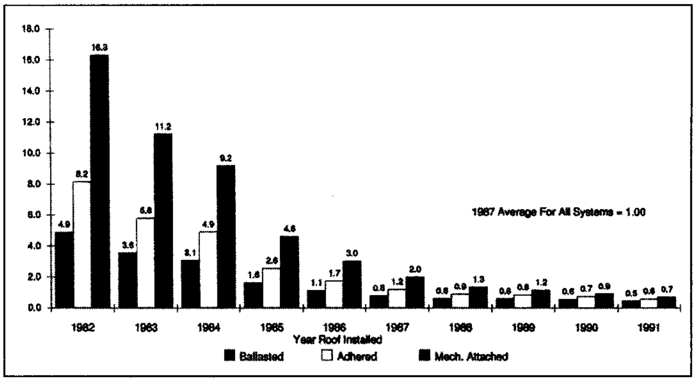

Chart 4: EPDM repair costs by system type: First five years of service (indexed cost per square meter).

early years of the database, these three systems now provide almost identical performance. In all likelihood, this change is related to the previously identified improvements in field seaming technology combined with the relative frequency of roof seams for each of these systems. Although ballasted roof systems typically use EPDM membrane panels up to 15.2 m (50 feet) wide by 30.4 m (100 feet) long, fully adhered and mechanically attached systems use smaller roof panels with more field seams. Given the high repair costs associated with field seams in the early years of the database, it is reasonable to infer that roofs with a large number of field seams will be affected the most by seam performance. As the performance of the field seams has improved, however, the number of field seams in the EPDM roof system has become a less critical factor, narrowing the differences in system performance. It is also likely that improvements in the strength and durability of fasteners used in fully adhered and mechanically attached systems have also contributed to this favorable trend.

Maintenance Costs by Contractor Status

Chart 5 provides insight into the contribution of the steady improvements in applicator workmanship since 1982. This chart separates the performance of roofs installed by contractors who are still active in the manufacturer's licensing program as opposed to contractors who are no longer licensed by the manufacturer. Although the differential between these two groups is not as dramatic as some other comparisons in this study, this chart certainly indicates that workmanship and skill of the manufacturer's applicator base has improved continuously during this period.

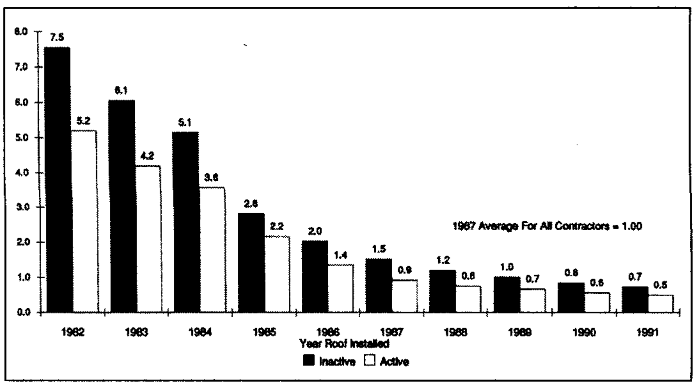

Chart 5: EPDM repair costs by contractor status: First five years of service (indexed cost per square meter).

EPDM ROOF SYSTEM PERFORMANCE: FUTURE TRENDS

Long-Term Service Life

The ten-year actual and projected repair costs from Charts 2A through 2H are summarized in cumulative form in Chart 6. As illustrated by this chart, the five-year performance improvement trends previously identified in Chart 1 appear to be equally valid for a ten-year period. In addition, the relatively flat slope of the annual repair cost curves for roofs installed since 1988 (Charts 2E through 2H) may be a good indicator that the repairs made to these roofs have been reasonably effective and that these roofs will continue to perform with minimal repair or service expense well beyond the nominal ten-year warranty period.

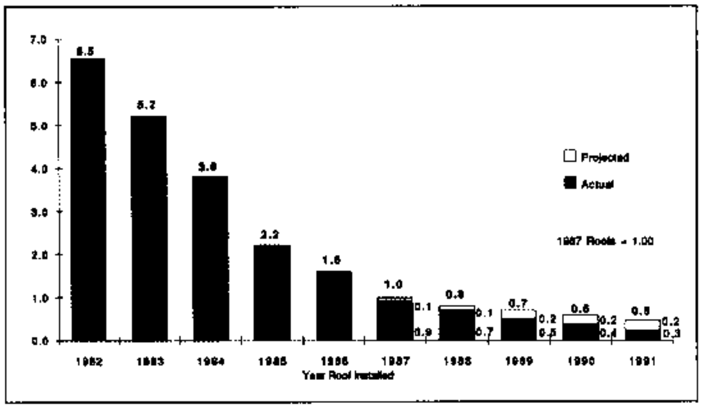

Chart 6: *Actual/estimated EPDM repair costs: First ten years of service (indexed costs per square meter).*

Future Component Improvements: Seam Tape

In addition to component improvements previously discussed, the manufacturer began the active promotion of seam tape along with a high-solids primer starting in 1993. Recognizing that field seams were still the largest contributor to repair costs, the manufacturer expected that this new technology could provide even further improvements in field seam performance. Although the actual repair cost data for this new technology are still too small to evaluate fully, it does appear that seam tape is already making a significant improvement in the level of service calls made during the two-year initial contractor repair period. Chart 7 shows the relative number of service calls reported to the manufacturer per unit roof area made during the first two years of service.

As illustrated by the chart, the frequency of calls for roofs using seam tape is 43 percent to 46 percent lower than the frequency of calls for roofs using liquid splice adhesive. Given this significant difference in initial service calls, it is very likely that the historical improvement trend for EPDM roof performance will continue.

Re-cover vs. Tear-Off

Much discussion has occurred in recent years regarding the relative merits of tear-off versus direct re-cover for reroofing applications. Chart 8 shows the five-year performance trend for these two approaches to re-roofing, along with the trend for new construction projects. Although the repair costs of re-cover projects were much higher than reroofs with tear-off in the early 1980s, this difference had almost disappeared by the end of the decade. Based on the previous analysis of component trends, it is likely that the primary cause for the inferior performance of EPDM re-covers in the 1980s was the early neoprene adhesive technology, which was susceptible to internal moisture attack. As improvements in adhesive technology have been made, however, repair costs for re-cover projects have declined significantly. Some of the performance improvement for EPDM re-cover projects also is likely the result of a general industry trend toward better analysis of the condition of existing roofs before the decision is made to perform a re-cover. Based on the contributions of improved adhesives and better roof analysis, it is very likely that EPDM re-covers, when judged appropriate for existing roof conditions, will increase in popularity, especially as costs associated with tear-offs, such as landfill charges, continue to escalate.

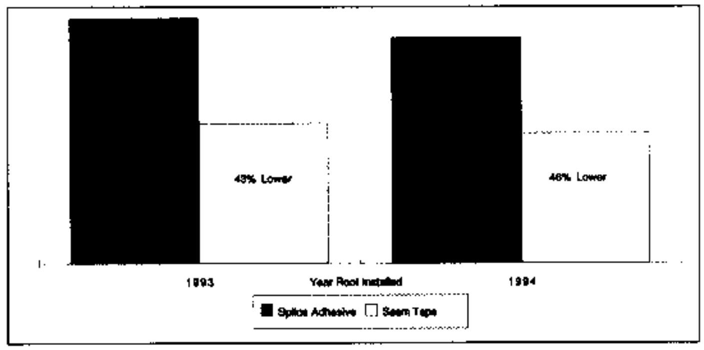

Chart 7: *Seam tape vs. splice adhesive: Comparative percentage of roofs with call-backs during first two years.*

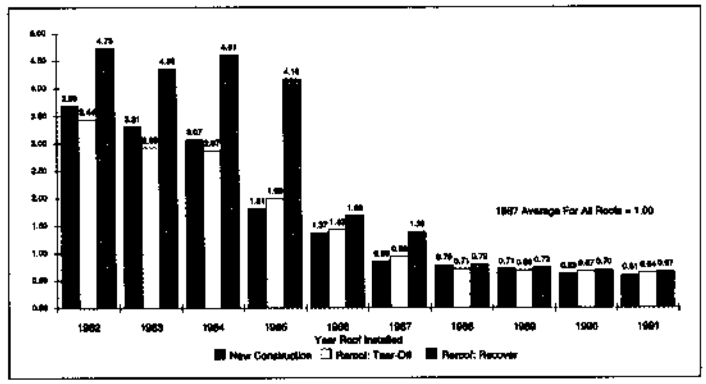

Chart 8: *EPDM roof repair costs: New construction/tear-off/re-cover; First five years of service (indexed cost per square meter).*

EPDM AND MODIFIED BITUMEN PERFORMANCE: INITIAL TRENDS

As mentioned previously, the database used in this study also contains millions of square feet of modified bitumen roof systems installed since 1987. Chart 9 shows the five-year repair costs for these modified bitumen systems as compared to the EPDM roofs in the database. Not only are the costs of the modified bitumen systems much higher than EPDM systems installed in the same year, but the presence of a downward trend is less certain. Chart 10 expands on this evaluation by showing the comparative performance of the two major types of modified bitumen roofs: APP and SBS.

Before any discussion of these comparative trends can be undertaken, it is important to identify the basic design char-

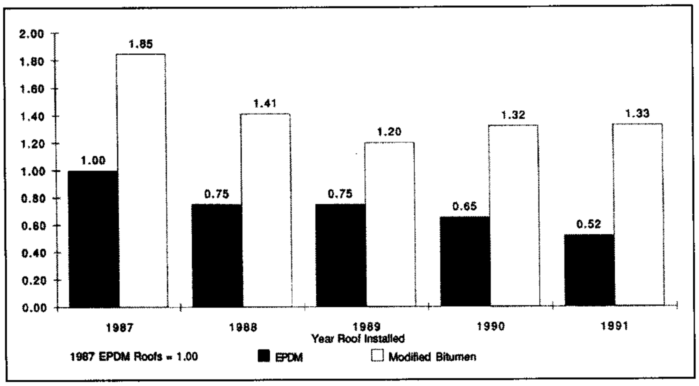

***Chart 9:** EPDM/modified bitumen repair costs: First five years of service (indexed cost per square meter).*

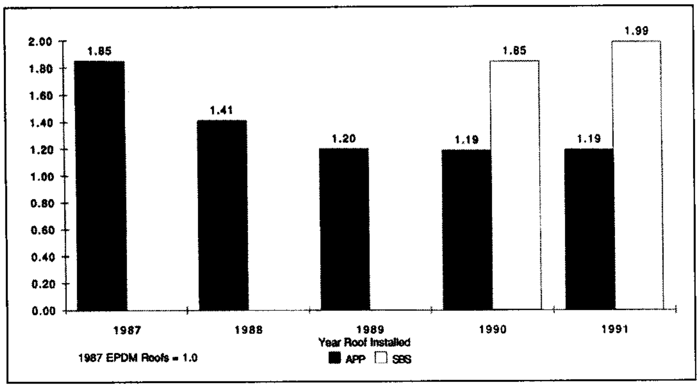

***Chart 10:** APP/SBS roof repair costs: First five years of service (indexed cost per square meter).*

acteristics of the modified bitumen systems included in the manufacturer's database. Almost all of these systems, both APP and SBS, consisted of a single layer of modified bitumen cap sheet installed directly over a mechanically attached non-modified base sheet. In terms of waterproofing redundancy, these modified bitumen roofs are similar to single-ply roofs, except that the frequency of field seams is much greater for the modified roofs (one field seam every meter) as compared to typical EPDM roofs (one field seam every 3 to 15 meters). Because the great majority of modified bitumen repair costs incurred to date by the manufacturer are related to seam performance, it is likely that much of the difference in performance between the manufacturer's modified bitumen systems and EPDM systems is related to the difference in the frequency of field seams. It is also likely that the lower performance for the manufacturer's modified bitumen systems is also related to the lack of waterproofing redundancy as compared to other asphalt roof systems, such as 3- or 4-ply built-up roofing or multiple-ply modified bitumen systems. In fact, the performance of the systems in this database would appear to provide strong support for multiple-ply applications for asphalt systems.

SUMMARY

Although it is not possible to identify the exact cost of roof system repair, indexing techniques provide a valuable tool to measure and analyze relative changes in the performance of roof systems over time. General performance trends can also be further analyzed by comparing the relative repair costs of various roof populations or system components.

In the case of EPDM roof systems in this database, it is clear that significant performance improvements have been made during the past fifteen years, both in the design of system components and in the general effectiveness of installation practices. In view of the year-to-year performance curves for recent EPDM systems, it is also clear that these systems should provide additional years of service well beyond the nominal warranty period. The initial information regarding the performance of seam tape indicates that even further improvements in performance are likely.

In the case of the modified bitumen roof systems within this database, it is apparent that applications of a modified bitumen cap sheet over a mechanically attached base sheet, which provide no redundancy of waterproofing layers, do not offer a the same level of long-term performance as the EPDM roofs in the database. The performance of these one-layer modified bitumen systems would also appear to support the continuation of more traditional redundant approaches to asphalt roofing, whether using multiple layers of modified bitumen plies, nonmodified roofing felts, or a combination of modified and nonmodified plies.

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