STRESS talk 2012

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technical excellence

1972 2012

contents

STRESS ENGINEERING SERVICES INC.

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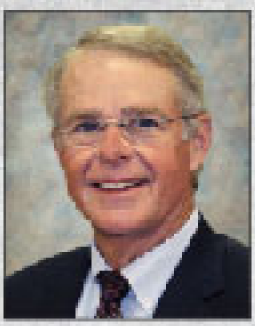

President's Message

In November our company will celebrate its 40th anniversary. As one of the firm's co-founders, along with Ray Latham and Harry Sweet, our initial focus was on helping clients drill high-pressure gas wells and providing certified stress reports for components in nuclear power plants. Over the years, our services have greatly broadened along with our client base. Last year, we were privileged to serve 788 clients worldwide.

In 1980 we opened our first test laboratory at the urging of Tom Asbill. The combination of full-scale testing and advanced analysis was well received by clients and dramatically expanded our testing services. Our three test labs in Houston, along with others in Cincinnati, New Orleans, and Calgary, employ over 83 technicians. Tom's ambitions have made Stress Engineering a valued service provider to many clients, particularly in the field of testing threaded connections for oilfield service.

Sadly, in October 2011 we lost Tom to cancer. He will be missed greatly. In keeping with Tom's valued work ethic and concern for the welfare of our technicians, Randy Long now oversees all of our Houston test labs. Tom was also our Senior Vice President, and Jack Miller has assumed the role of Executive Vice President.

Each of our service areas reported significant successes and improvements in 2011. To ensure that we continue to deliver a high level of quality and service, we are asking our clients for feedback on our performance on each project. Please take the time to answer this survey. We sincerely want to be a better service provider to you, and this data will help us achieve that goal.

I am also pleased to announce that our Quality Management System, under the direction of Earl Hudspeth, resulted in an ISO 9001 certification for our Cincinnati office. The other areas of the company are working toward the same goal.

We are rapidly expanding our staff to meet the strong demands for our services with new, intelligent young people along with experienced professionals who are quickly absorbing the culture of internal cooperation of an employee-owned company. We also remain extremely committed to our initial principles of providing high-quality technical and problem-solving services.

As we celebrate our 40th anniversary, all of us at Stress Engineering Services want to thank you, our clients, for your support and friendship. We pledge to continue to work hard to provide you the "right answers on time."

Thanks!!

Joe R. Fowler, Ph.D., P.E.
President
Stress Engineering Services, Inc.

Analysis of Measured Data for Offshore Systems

Scot McNeill, Ph.D., P.E.
Puneet Agarwal, Ph.D.

For offshore systems, measured data contain a lot of valuable information about system performance and integrity. Accelerometers, angular rate sensors, strain gages, and Global Positioning Systems (GPS) can be used to characterize the response of an entire Floating Production System (FPS) in various weather conditions. Some of these instruments can also be used to record the behavior of subsea or subsurface equipment, such as risers, jumper, manifolds, and pipelines in cyclic loading environments. Additionally, anemometers, wave radar, current meters, and pressure transducers can be used to measure the environmental or internal loading conditions.

As good quality, high precision instruments are readily available on the market place, the challenge does not lie in the capability of instrumentation for most engineering applications. Instead, the difficulties in design and implementation of a beneficial integrity management program can be summarized as follows:

- **Understanding what performance parameters are important**
- **Selecting the appropriate instrument for each performance parameter**
- **Designing the data acquisition system to compliment the capabilities of the instrumentation**
- **Processing and analyzing data to extract all the useful information from the entire set of instruments**

These issues are straight-forward to resolve. However, it is necessary to enlist engineers with knowledge and experience in signal processing and data acquisition, as well as mechanics of offshore systems in the program. The engineering team at Stress Engineering Services combines decades of knowledge and experience in these areas, allowing for a comprehensive solution for structural monitoring and integrity management.
In this article, we focus on signal processing and data analysis. Examples are provided where assessment of measured data is an integral part of the engineering analysis performed. Examples are provided for risers, floating systems, and subsea jumpers.

REAL-TIME RISER FATIGUE MONITORING

Ever-increasing emphasis has been placed on monitoring of marine riser systems for extremes, fatigue, corrosion, etc. by both oil companies and regulatory bodies. For drilling risers, the drilling contractor is expected to have a riser management plan or joint rotation plan that can adequately identify the joints of concern which can be either rotated in the riser string or can be "pulled" for inspection. Performance of production risers should be verified to ensure adequate design, especially when new design features or operating conditions are encountered. In addition, rough conditions or high currents can limit drilling and production operations and raise safety and environmental concerns. Real-time monitoring provides direct information on the performance of the riser on-demand, enabling operators to make informed decisions.

Stress Engineering Services has recently developed a complete system for riser vibration monitoring [1]. The instrumentation consists of a series of Subsea Vibration Data Loggers (SVDLs) connected to the top-side data acquisition system via a fiber optic cable. Each SVDL houses a triaxial accelerometer and biaxial angular rate sensor with the associated electronic boards in a one atmosphere environment. The SVDLs and data cable are deployed and retrieved with the riser. Riser motions and statistics are displayed in real-time on the vessel. Custom software computes stress and fatigue damage updates every 15 minutes for on-board display and archiving. The first deployment of the system is scheduled around mid-year 2012.

The instrumentation system utilizes robust, deployable accelerometers and angular rate sensors and does not require direct strain measurements (though strain gauging critical areas is recommended). Therefore an algorithm had to be developed to calculate stress time histories and determine fatigue damage from the measured riser motion. The algorithm developed employs Modal Decomposition and Reconstruction (MDR) of the measured data, whereby the recorded riser motions are decomposed into modal responses (response of individual modes) and stress time histories are reconstructed from the modal responses and mode shape curvatures. Details of the procedure can be found in [1, 2].

The algorithm was validated by numerical simulation of several different riser configurations and current environments as well as measured test data of a slender, flexible riser from the Norwegian Deepwater Program (NDP) [3]. The validation with the NDP data involved comparing fatigue damages derived from measured accelerations with damages computed from direct measurements with strain gages that were placed at different locations than accelerometers. Results from NDP test 2120, uniform current, are briefly presented here. Figure 1 illustrates the position of the 8 accelerometers and 24 strain gages as well as the current direction.

Average Power Spectral Density (PSD) plots are shown for the X-direction (in-line) and Y-direction (cross-flow) in Figure 2. Notice that the fundamental in-line response frequency is twice that of the fundamental cross-flow frequency and the third and fifth harmonics are present, as expected for VIV of long, flexible risers.

The MDR algorithm was used to reconstruct the stress time histories along the entire riser length, at several locations around the circumference. Standard rainflow cycle counting and S-N methods were then used to compute fatigue damage rates. Reconstructed fatigue damage rate curves are shown along with values obtained from the measured strain gage data in Figure 3. The method developed clearly allows for accurate stress and fatigue damage prediction using a limited number of deployable sensors.

FPS PERFORMANCE MONITORING

Floating production systems represent a major financial investment. Structural integrity and performance in harsh environmental conditions is necessary to ensure optimized production. Many operators have realized the importance of continuously monitoring metocean conditions and the FPS response to support design verification efforts, evaluate future expansion capacity,

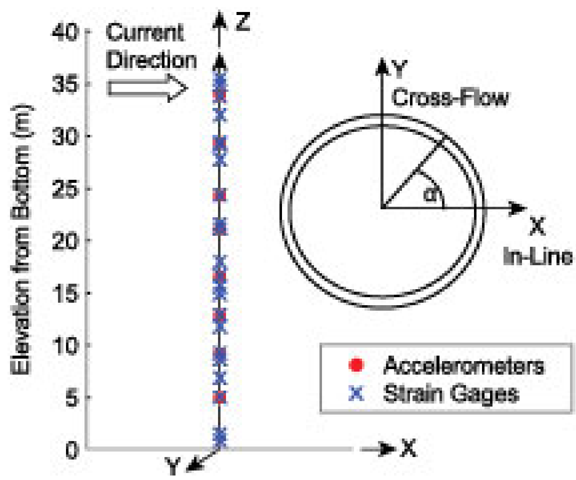

Figure 1: Sensor Elevations

and extend the service life of the asset. To maximize the impact of the data measurement program requires integrating knowledge of the environment and FPS response with proper data cleansing and analysis techniques.

Data is often used in validating predictions from numerical simulation. Two examples are presented, comparing predictions to measurements. Figure 4 illustrates measured significant wave heights to hindcast values during a major hurricane in the Gulf of Mexico. Measured data was recorded using downward-looking wave radar, attached to the deck of a semisubmersible platform. Since the platform moves under the influence of wave, what is actually measured

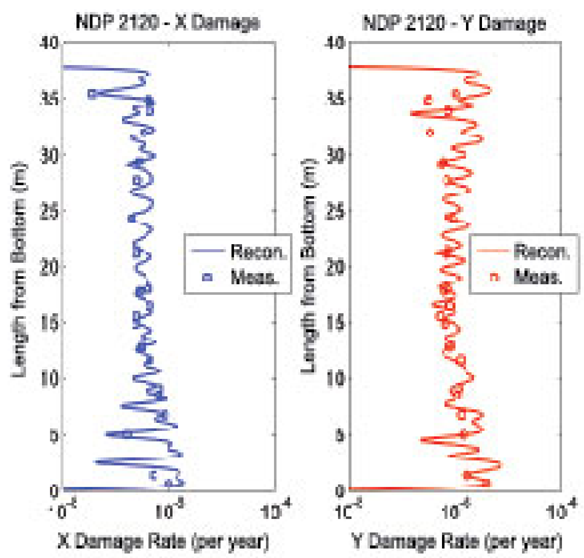

Figure 2: Measured VIV Acceleration Spectrum

is the relative wave elevations as seen by the moving vessel (blue line). It was necessary to remove the platform motions from the measured wave radar data to calculate the absolute wave elevations (green line) for direct comparison to hindcast data (red line). Vessel motions were recorded using a triaxial accelerometer and angular rate sensor. These motions were then transformed to the wave radar location to remove the vessel motions from the wave radar data. By comparing the difference between the blue and green lines, it can be seen that the correction for vessel motion becomes larger as the significant wave height increases.

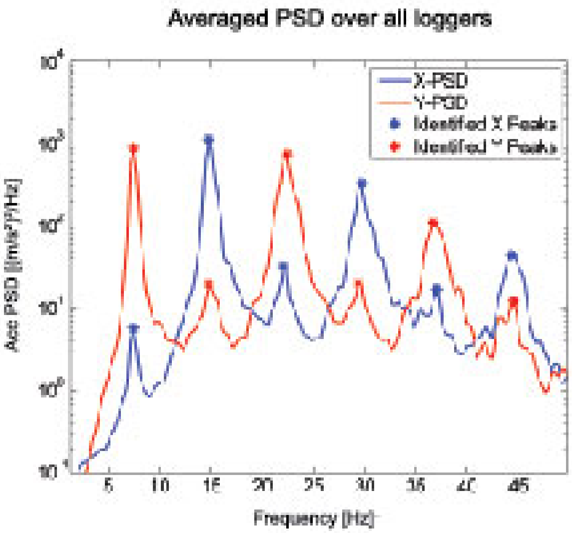

Figure 3: Measured and Reconstructed Fatigue Damage Rate

Predicted motions of a Spar platform, obtained using the in-house RAMS software, are compared to measured data in Figure 5. Here the PSD of the pitch rate is compared between the two sources. Standard signal processing methods were used to obtain a smooth PSD estimate from the measured data. The low-frequency peak at the pitch natural frequency (0.02 Hz) and the broader peak for wave frequency response (0.1 Hz) are clearly depicted. Notice that the measured peak at the pitch natural frequency is slightly flatter and broader than the predicted peak. This is because data processing parameters were set up to smooth the wave-frequency response at the expense of low frequency resolution. The two frequency bands can be handled separately to optimize parameters for each peak to avoid this artifact; though it is usually sufficient

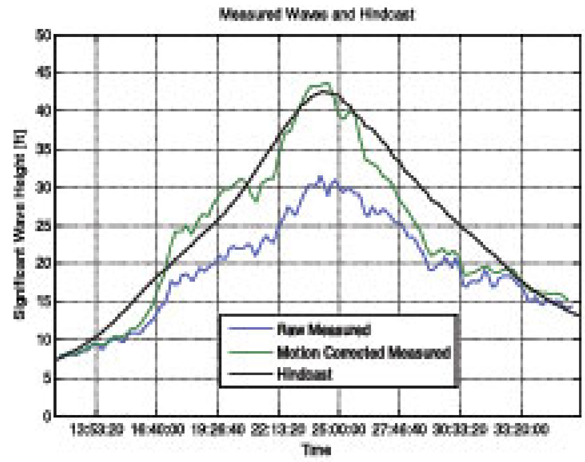

Figure 4: Measured and Hindcast Wave Height in Hurricane Conditions

to ensure that the area under each curve compare well for the resonant and wave frequency bandwidths.

SUBSEA VIBRATION MONITORING

Flow Induced Vibration (FIV) of piping systems is generated by flow restrictions such as elbows, tees and partially closed valves. Vibrations can be severe enough to impose restrictions on production rates. Predictive analysis of subsea piping is limited due to lack of empirical data for common geometries and flow conditions. An alternative analysis approach, combining in-field measured data and Finite Element (FE) models can be taken to assess stress and fatigue damage. To obtain accurate results, understanding the nature of random response and applying appropriate data analysis methods are imperative.

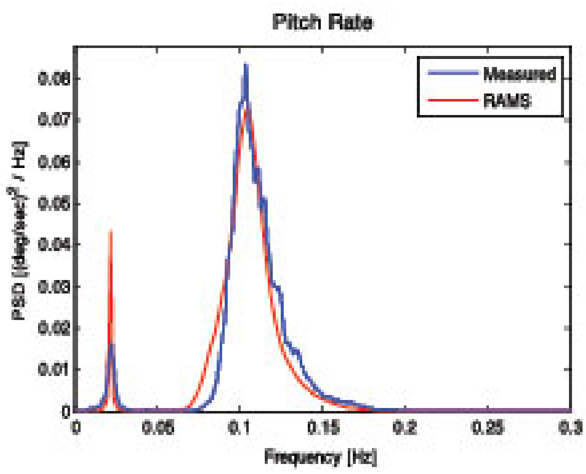

Figure 5: Measured and Predicted Pitch Response in Winter Storm Conditions

Many of the analytical tools and techniques developed for random vibration induced fatigue assume that the dynamic stresses are stationary, narrow-banded and normally distributed. These assumptions must be validated before application of such methods. Measured acceleration PSD data from a subsea well jumper is shown in Figure 6. Three vertical, three horizontal in-plane and three horizontal out-of-plane channels were recorded. The data revealed that the dominant direction of vibration was vertical (green red and yellow lines). Though many modes were excited, only two modes contributed significantly to vertical acceleration (4.5 Hz and 6 Hz modes). Computation of the statistics, including bandwidth parameter, skewness and kurtosis confirmed that the vibration is classified as narrow banded and normally distributed.

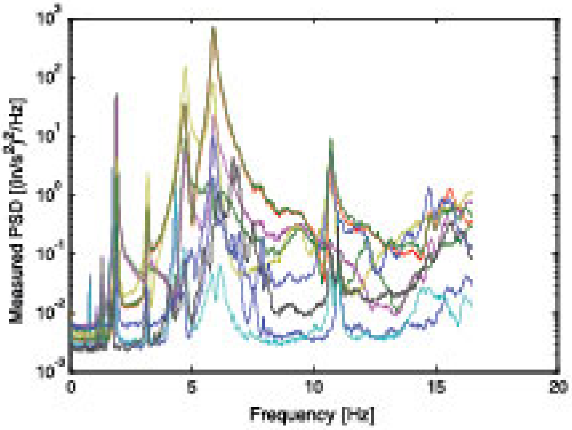

Figure 6: Measured Acceleration Spectrum for Subsea Jumper in FIV

Under the assumptions, the peaks or cycles in the acceleration time history should follow a Rayleigh distribution. This is confirmed by comparing the rainflow cycle histogram to the theoretical Rayleigh distribution.

After verifying the nature of the random vibration, the forcing function for the FE model was determined such that the predicted acceleration PSD matches the measured acceleration PSD for all peaks (vibration modes) and all sensors. The predicted acceleration PSD, from FE analysis, is shown in Figure 7. The resulting analytical stress PSD is then re-examined to ensure that it is narrow-banded before applying the classical spectral fatigue damage calculations. More information on the method and applications can be found in [4].

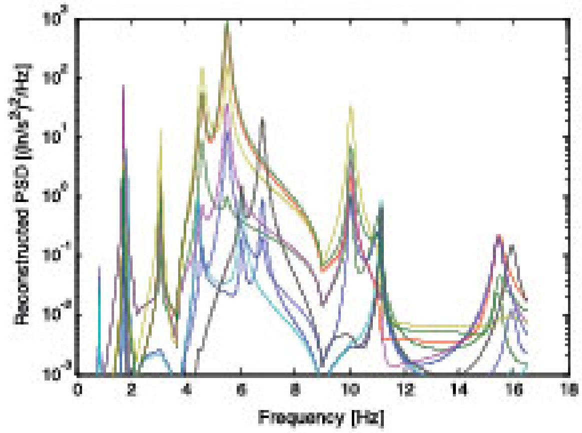

Figure 7: Predicted Acceleration Spectrum for Subsea Jumper in FIV

CONCLUDING REMARKS

Data recorded on offshore systems is taken from many different instruments, each with its unique sources of inaccuracy. The errors in each data set must be understood and carefully removed before any further processing or analysis can be performed. At Stress Engineering Services, we employ advanced data cleansing, signal processing, and statistical analyses to draw conclusions on the performance of offshore systems, which are strongly evidenced by the data. Combining our data analysis capabilities with knowledge and experience with offshore systems, we can provide information you can rely on to maximize the utilization of floating and subsea systems.

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[2] S. McNeill and P. Agarwal, Efficient modal decomposition and reconstruction of riser response due to VIV, In: Proceedings of the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering OMAE2011, June 19-24, 2011, Rotterdam, The Netherlands (OMAE 49469).

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Testing at Stress: The First 40 Years

Randy Long, P.E.

In 2012, Stress Engineering Services, Inc. (SES) will celebrate a major milestone—our 40th anniversary of doing business. SES began operations in 1972 as Sweet, Latham & Fowler. The initial technical focus was performing design reviews for components used in the nuclear industry. However, that narrow focus soon changed! After setting up shop in Houston, the firm started working with oil companies and oil patch equipment providers to help solve their most challenging engineering problems. At first, our work was primarily in the areas of design and analysis. After a few years, our first testing jobs were undertaken as an essential service to prove that the equipment performed as indicated in the analyses and was suitable for the intended service. This effort was led by Tom Asbill, the founding father of our testing business, and one of the best test engineers you will ever meet.

Longtime lab manager Bob Wink installing instrumentation packages developed and deployed by SES

Technician Barry Bailey working in Stress Engineering's first testing laboratory

Our first dedicated test lab was set up in the late 1970's. It was a humble beginning – 1,250 square feet and no overhead crane. One of the first big jobs was monitoring the tow-out of an offshore pipeline from the assembly area on the beach to the final location.

Testing work increased steadily in the early 1980's with special tests such as pipe swivel life cycle testing and the acquisition of our first load frame. The first load frame had an axial load capacity of 800 kip and was used to perform SES's very first tests of threaded pipe couplings. Data acquisition was performed via a state-of-the-art system V/E 220 complete with a paper tape printer that printed strain readings at about 30 readings per minute!

Our first overseas data acquisition work was in 1984-1985 monitoring pile driving offshore Italy and installing an instrumented location system on a pile driving barge in Venezuela. By this time, the lab had grown to twice

Stress Engineering's first test frame

V/E 220 Data Acquisition System

the original (small) size, but was limited by the lack of space and especially by the lack of an overhead crane. In 1985-1986 the company relocated both its lab and offices to the current Houston location (our Building 3 at 13800 Westfair East Drive). This building included over 40,000 square feet of space, with 15,000 of that in the lab area. We did not occupy even one-third of the lab area or the offices when we moved in, and were certain this was more room than we could ever need.

Stress Engineering Services Test Lab - 1986

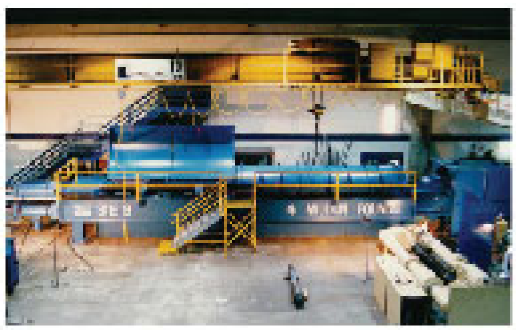
As some readers may remember, the oil patch business was very slow in the late 1980's. We worked very hard to find projects and keep busy. During this time we started our first analysis work along with testing for a major consumer products company. It turns out that threaded details are not only used on oil patch pipe – they are common on bottles of bleach, soft drinks, etc, and it is equally undesirable for these to leak. We performed impact tests on these bottles and recorded internal pressure data at high rates to verify our analysis results. This work ultimately led to the establishment of our Cincinnati, Ohio office where consumer products remains one of their main practice areas.

The 1990's were a busy time for all of SES. The first tension leg platforms were installed in the Gulf of Mexico and many other technological advances were

Cincinnati Testing Laboratory

developed. Testing of this equipment kept our test labs busy and growing. We added a 4 million pound load frame and other smaller capacity frames, as well as a tendon test facility that could test tendons and tendon flex elements to loads up to 6 million pounds and perform fatigue tests on these critical platform components.

In 2000, we purchased our worthy competitor Mohr Research & Engineering and joined forces and equip-



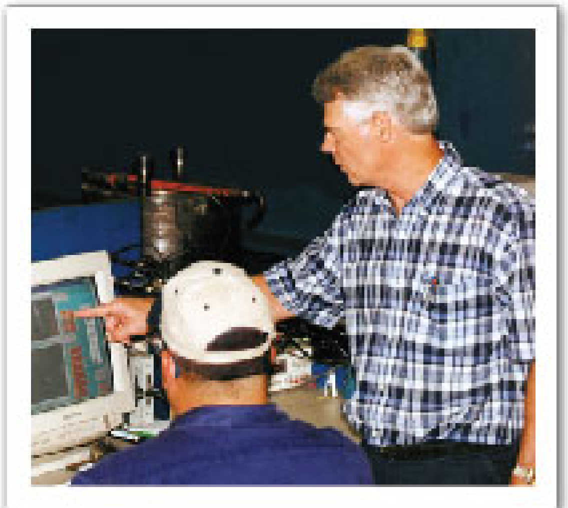
4 million pound load frame

36" sample in a Resonant Bending Fatigue Machine

ment to provide improved external pressure testing and other capabilities to our clients. The Mohr Division was relocated to a new lab/office building adjacent to the main SES facility to encourage cooperation and sharing of resources. In 2004 we added an extension to the original Building 3 lab that more than doubled its size. We also added a 6 million pound capacity frame and a resonant bending fatigue test facility. These fatigue machines take advantage of near-resonance response to greatly accelerate fatigue testing on full-scale pipe samples. For example, in 1990 it took two months to fatigue test a tendon pipe to about 2 million cycles; now we can complete that many cycles in one day with a resonant machine with a corresponding reduction in test costs.

Aerial view of Waller Testing Facility

In 2008 it became apparent that we were running out of room at the Houston campus. We purchased 92 acres for a new test facility near Waller, TX (about 25 minutes away from our main office). Our growth in the last few years has been primarily at this facility and features two test lab buildings with a third under construction. These labs perform full-scale testing similar to the Houston locations, as well as in harsh environment (H_2S, etc.), small-scale fatigue testing, and many other types of tests.



Tom Asbill and technician monitor a load test

We lost Tom Asbill to cancer in November 2011, but he was active to the end with the labs and testing at SES. Also, Bob Wink is retiring in March 2012 after 38 years of dedicated service to SES and its clients. These men were instrumental in developing and growing our testing capabilities from a modest start to the world-class facilities we operate today. Both have helped form the culture at SES which is best summed up as doing whatever it takes to provide our clients "the right stuff on time," whether that involves testing, analysis, or design. They will be sorely missed.

randy.long@stress.com

Robust Engineering:

A Forward-Looking Approach to Medical Device Reliability

Mark Bennett, P.E.

The medical industry is under increasing pressure by regulatory bodies and consumer groups, as well as the self-imposed goals of manufacturers to increase the reliability of medical devices to extremely high levels.

The traditional approach in this industry is to evaluate reliability through physical testing, historical failure information, or other forms of performance-based data. This traditional approach is rearward looking in that it can only evaluate the performance of a device or subsystem after it is designed. Due to the high costs and long schedule delays caused by redesign, it is often too late at this point in the development to improve the reliability of a device in any significant fashion. As a result, products are released with lower than desired reliability, and the device companies can subsequently be affected for the life of the product. Stress Engineering Services, Inc. is bringing a forward-looking approach to medical device reliability where higher reliability is designed into the product from the start, which results in both improved performance and lower long-term cost. This approach involves working to assure reliability beginning in the design stages of the product and continuing through manufacturing.

Reliability is a statistical calculation of the probability a unit will survive beyond a prescribed time "t." In other words:

Reliability =1 – probability of failure at time t

A failure is anything that renders a product unable to meet its requirements. This includes all aspects of functional performance, user needs, aesthetics, etc. Functional failures include issues such as cracks, leakage, wear, and loss of accuracy. User failures involve interactions with the device where a user may not be able to read a display, push a button, or activate a function. Discoloration, delamination of labels, and inability to clean surfaces are examples of aesthetic failures. Regardless of the type, all of these failures are significantly impacted by activities occurring in the design phase of a project. Therefore, improving reliability should start during design.

Design activities impact reliability in several different ways. These include development and selection of various mechanisms or components in the device (e.g., springs, levers, bearings), the choice of materials, the manufacturing process used to produce the device, and how the product influences user interaction. To maximize reliability, all of these factors must be considered. However, there is no practical means to optimize a device, particularly a more complex system, for all requirements simultaneously. A systematic approach is required to identify which attributes are most important and what design features have the greatest influence on these attributes.

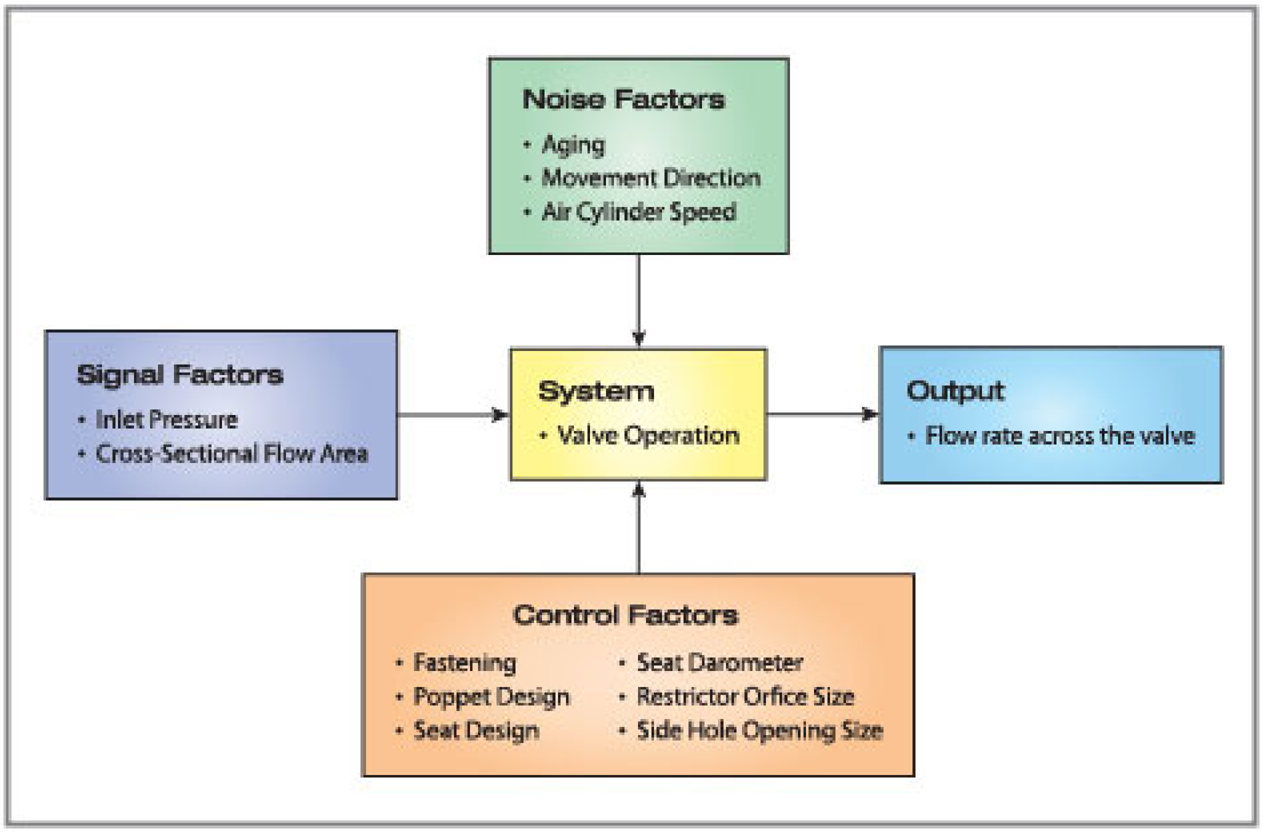
Identifying the most important attributes requires a high-level view of the device. This can be considered by filling in the blank in the following statement: "If the device doesn't do _________, nothing else matters." Whatever attribute or function you list in the blank becomes the highest priority and is addressed first in the effort to design for reliability. Following identification of the key attribute for the device, analysis is completed to understand how the various elements of design, materials, manufacturing, and use affect this function. This understanding of the influence of these design elements is leveraged to optimize the output of the device for the key attribute. After the primary function is optimized, other attributes can be addressed in priority order as long as they do not negatively impact the higher priority functions. Through this systematic process, the focus is placed on the most important items first and other performance aspects are addressed as time and resource availability permits. This approach results in higher product reliability. Robust Engineering is one of the systematic evaluation and optimization tools Stress Engineering Services, Inc. is utilizing to increase reliability in the medical industry. This approach has already proven extremely successful in the aerospace and automotive industries. Have you noticed the rarity of a breakdown of a modern vehicle on the highway? The key to this approach is development of a function model, or transform function, to understand how design, materials, manufacturing, and use affect the primary output of the device.

Failures, and therefore poor reliability, are the result of variability in these design, materials, manufacturing, and usage inputs. Robust engineering replaces the common approach of quantifying the symptoms of poor design and quality, such as tracking failure rate, investigating how failure occurs, and then determining how to fix it. Instead, by using the function model, robust engineering first identifies the factors (inputs) that have the most significant impact on the outcome of the target system. The method then indicates how to exploit those factors in order to control the process and deliver the desirable outcome—improved product performance and reliability. This approach drives the focus from "what's wrong and how to fix it" to "what's right and how to maximize it."

An example of a typical function model for a valve with a vibration issue is shown below . There are four main analysis groups associated with the function model. Three of these groups—signals, controls, and noise are inputs, while the remaining group represents the outputs. These main analysis groups feed the transfer function and define the valve's operation. In this case, the transfer function is based on engineering first principles derived by considering energy flow in the system. In this example, the transfer function is an equation taking into account the cross-sectional flow area and the square root of the inlet pressure to calculate the flow rate. By optimizing the transfer function, any energy not performing the desired work of throttling flow (loss) is reduced. This eliminates the undesired condition of vibration.

Using this approach, the "cause" of the vibration is identified as unintended energy loss in the valve. Energy loss was eliminated by optimizing the signal-to-noise ratio (S/N) for the transfer function using Design of Experiments (DOE) testing, thus focusing on what's right (the flow rate across the valve) and how to maximize it.

The direct output of the Robust Engineering function model is the S/N for the process or subsystem under evaluation. Robust engineering utilizes tools, such as DOE, to evaluate the effects of various input parameters (both controls and noise) on the target output. DOE was employed in the example above because the valve already existed. However, parameter design can frequently be done through simulation using any number of tools, including finite element analysis (FEA), dynamic systems models, computational fluid dynamics (CFD), or



Example Function Parameter Diagram [1]

engineering calculations, in combination with partial system prototypes. The ability to use simulation tools facilitates maximizing S/N and verifying the design assumptions early in the process, when the cost to implement significant changes is minimized and physical prototypes are not yet available.

As the development proceeds, it is often necessary to execute testing on certain components and sub-systems to collect data to refine the inputs into the transfer function models, or to verify expected performance. The testing is typically set up to evaluate the worst possible assemblies, as these will provide the limits of reliability for the system. Eventually, the data collected in the Robust Engineering process are used to identify which confirming tests need to be conducted to verify the expected reliability. A key benefit of the Robust Engineering approach is to facilitate reliability testing on larger portions of the overall system, thus reducing the cost and time required for determining reliability.

In summary, maximizing medical device reliability requires working to design in high reliability from the start of the development process. This includes considering the effects of design, material selection, manufacturing, and use, as well as the variability of each of these elements on the key performance outcomes of the device. Robust Engineering represents a proven methodology for delivering high reliability products, and can be directly applied to medical device development. It is important to understand that Robust Engineering, or other forward-looking reliability tools, do not replace traditional reliability evaluation methods. Instead, they can be used to provide product designs that are inherently more reliable and require less of the costly, time-consuming testing often required. However, Robust Engineering requires a greater level of involvement by the reliability team early in the process to maximize the reliability inherent in the component and sub-system designs.

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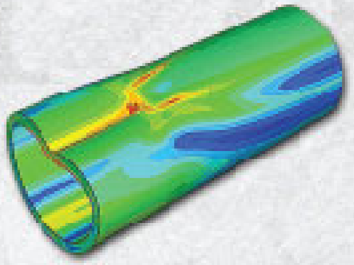
1972
Company is founded. Initial work included certifying stress reports of nuclear power plant equipment and engineering support for deep gas wells, refineries, and chemical plants.

1975
Started work on a frequency domain marine riser analysis simulation program which later became DERP.

1980
First Test Lab opened to support the development of instrumentation bottles used to measure strains during installation of a towed out offshore pipeline.



1985
Began offering electrical engineering and instrumentation services

1986
Moved Houston office to 13800 Westfair East Drive (current location) with combined offices and test lab.

1988
Started work in the consumer products industry with the application of finite element analysis to consumer products.

1989
Designed and began construction on a 4 million lb. tendon test facility and flex join facility.

1990
Began pipeline research work and collapse testing research.

1991
Began metallurgical services and computational fluid dynamics services.

1994
Began fire testing and induction heating services in our laboratory

1996
Built new office/laboratory in Cincinnati. Opened New Orleans, Louisiana office to serve refineries and chemical plants.

1998
Began acoustic emission NDT services and polyester mooring testing services.

1999
Purchased Mohr Research & Engineering. Development of RAMS analysis software. Began resonant fatigue testing services.

2001
Acquired the U.S. assets of ERA Technology to enhance our services in refineries and chemical plants. Began coke drum monitoring services. Opened a metallurgy lab in New Orleans.

2003
Construction is completed on the new 33,000 sq. ft. office and lab facility for the Mohr Division.

2004
Stress Subsea Inc. was formed to offer design and project services for subsea production systems in conjunction with our Floating Systems Practice.

2005
The Houston test lab 17,500 sq. ft. expansion is completed. Unveiled Stress Engineering's Employee Stock Ownership Plan.

2006
Expanded vibration analysis and field testing services. Added cold testing facility, thermal and insulation testing facility.

2008
Purchased dedicated facility for Acoustic Emission and Measurement & Control practice areas. Houston metallurgical lab adds advanced scanning electron microscope. Deepwater RUPE consortium begins.

2009
Opened 41,000 sq. ft. LEED office building/ conference facility in Houston and a 34,000 sq. ft. laboratory in Waller, Texas featuring a corrosive materials test lab.

#1 Best Companies to Work for in Texas 2010

Best Employers in Ohio 2010

2010
Awarded #1 Best Place to Work in Texas and #2 Best Place to Work in Ohio. Named to Zweig White Hot Firms and Aggie 100 fastest growing Texas Aggie managed companies lists.

2011
Acquired Calgary, Alberta, Canada based Zeus Engineering and formed Stress Engineering Services Canada. Opened expanded office/lab facility in New Orleans and state-of-the-art creep testing lab in Cincinnati.

New Data Collection Devices

Stress Engineering Services, Inc. (SES) Measurement and Controls Division has designed several new products for collecting data in the field and in the lab. Two of the new systems are based on the National Instruments SCXI hardware platform. This platform has been frequently used by SES and our clients, so adapting this platform to the always-changing computer technology is a good choice for the near future. These systems are supported by both of our data acquisition packages – StrainDAQ and EasyDAQ.

The SES-1201 (Embedded Computer)

Features a minicomputer attached to the SCXI chassis and incorporates a USB interface to the computer.

- Minicomputer attached
- Windows XP embedded or Windows 7
- Preinstalled StrainDAQ version 11
- Easy hardware configuration
- Ideal for lab environments
- Up to 96 channels of input
- Configurable for strain gages, thermocouples, and all types of full bridge inputs
- Only requires a keyboard, mouse and monitor to operate

The SES-1202 (USB Interface)

The main benefit of this unit is that it is a highly field-ready system. The SES-1202 uses a USB interface for connection to a laptop or PC of the client's choice.

- Connection to laptop via USB
- Windows 7 including 64-bit compatibility
- Utilizes StrainDAQ version 11
- Up to 128 channels of input
- Configurable for strain gages, thermocouples, and all types of full bridge inputs

MobileDAQ

MobileDAQ's compact size and portability makes it ideal for field jobs. It is available in single cell and four cell units. The four cell unit features a table top box or Pelican case enclosure that can include a PC, monitor & keyboard/mouse.

- Single Cell - Up to 16 channels
- Four Cell - Up to 16 channels
- Various combinations of inputs (strain gages, full bridge sensors, and thermocouples)
- USB, Ethernet, and wireless options
- Two scan rate options [high rate (>100 Hz) and low rate (<100 Hz)]

Improving Our Quality

Earl Hudspeth and Greg Deskins

At Stress Engineering Services we are always investing in the future. Our employees understand that in order to maintain continued growth and success we must continually deliver the highest possible levels of quality and customer satisfaction.

In a recent survey of our clients, Stress Engineering Services earned a 98% overall customer satisfaction rating. While we are proud of this achievement, our objective is to achieve 100% customer satisfaction, and we are committed to utilizing the time and resources to make this happen. In addition, we continue to invest in the education and training of our personnel. This enables us to supply clients with the most outstanding knowledge and skill sets available.

A key tool that allows us to provide a superior level of service is a strong quality management system (QMS). We made a strategic corporate decision to maintain a well-designed QMS and are committed to making our system even better. We have improved and expanded our QMS to focus on varying industry needs, particular objectives, products and services provided, processes employed to enhance customer satisfaction, and improving our effectiveness to meet customer requirements.

To help lead the way in this strategic decision, we added Earl Hudspeth as our new Corporate Quality Director. Prior to joining Stress Engineering Services, he served as manager of one of the largest ISO 9001 quality management system certification body in the United States. Earl's combined technical/quality knowledge and experience give us the capabilities to take our QMS to the next level and beyond.

Areas of focus for improving our QMS performance are:

- **Increasing client loyalty**
- **Increasing repeat business and referrals**
- **Improving our flexibility and speed of response**

- **Reducing our costs and cycle times through effective and efficient use of resources to allow us to meet customer needs at a competitive price**
- **Establishing goals and objectives for continuous improvement in quality**
- **Investing in advanced technology to better serve our customers in the future**

Our QMS has allowed us to understand and fulfill customer requirements and to obtain required performance. Our strategy is to continually improve our processes based on objective measurements of quality while considering the future needs and expectations of our clients. The officers and managers of Stress Engineering Services have helped create a unity of purpose that has produced a corporate culture that encourages our staff to be fully involved in achieving those objectives.

In today's market, companies set high standards for the organizations they choose to fulfill their needs. We understand that the client is the one who ultimately determines the acceptability of our services. That is why we are fully committed to meeting the challenges of ever-higher standards and expectations by improving our QMS. We believe this provides the framework for continual improvements to enhance customer satisfaction and confidence in our ability to consistently meet or exceed your requirements.

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Updated Perspectives on the Use of Composite Materials to Reinforce Damaged Pipelines, Risers, and Piping

Dr. Chris Alexander, P.E., Julian Bedoya, P.E., and Brent Vyvial

For the better part of the past 20 years, Stress Engineering Services has been integrally involved in evaluating the use of composite materials to reinforce pipelines, risers, and piping systems for the oil and gas industry. During this time period we have evaluated more composite repair systems than any organization in the world. As a result, Stress Engineering Services is in a unique position to understand the competing technologies that make up this important sector of the energy industry, one that contributes to the safe operation of pressurized components.

Because of our experience, we are often asked about the performance of composite repair materials by a wide audience including regulators, operators, students/professors, and composite manufacturers and suppliers.

We thought it would be beneficial in this article to address some of the common questions that have been posed to us over the past two decades and provide readers with our perspectives, and more importantly, to describe how we have used full-scale testing to validate the performance of composite repair systems. The following sections provide insights and perspectives on four questions dealing with critical subjects related to composite repair systems.

Are Composite Repair Systems A "Permanent" Solution?

Undoubtedly, this is the most often-asked question. The use of the word "permanent" is difficult to interpret from an engineering standpoint; however, its usage dates back to regulations governing composite material usage issued in 2000 by the Office of Pipeline Safety. The problem with the word "permanent" is that it is somewhat subjective—permanent means something different to practically everyone. A better requirement for any repair solution is to dictate that it meet or exceed the long-term service requirements of the pipeline or piping system on which it is installed. This approach is not only better technically, but also provides composite repair companies with a defined design condition.

Stress Engineering believes that the following should be considered with respect to the long-term performance of composite repair solutions.

- As part of the design package that every composite repair company should possess, a battery of tests should have been conducted to determine the limit state capabilities of that repair. For pipelines, this means that a repair should have been tested for specific anomalies (i.e., corrosion, dents, etc.) with destructive testing including burst and pressure cycle fatigue tests. Once these types of tests are completed, then the manufacturer can provide a design solution for operators.
- Operators must be able to define the actual operating conditions of their system. This includes pressure cycle data, as well as defining (if possible) any additional loading including temperature changes of the line and potential soil movement.
- Once the limit state conditions of the system have been established and loads are defined, a composite repair system can be optimally designed to meet the service requirements of a particular system.

To assist the reader in applying these concepts, an example problem is provided. A composite repair system was used to repair a 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion. The repair was pressure-cycled from 890 to 1,780 psi (stress range of 36% specified minimum yield strength (SMYS)) and failed after 767,816 cycles had been applied. From this test result, a design condition is established by dividing the cycles to failure by 10, resulting in a design fatigue life of approximately 76,000 cycles. A liquid transmission pipeline company operates a system with corrosion on the order of 75% of the wall thickness that cycles approximately 1,000 cycles per year at a pressure range of 36% SMYS. The corrosion needs to be repaired. Using the pipeline service life condition, as well as the composite repair design life, the long-term design life for the repaired corrosion is 76 years (76,000 cycles divided by 1,000 cycles per year). This approach is far more technically defensible and accounts for material degradation, as opposed to merely defining a composite repair solution as "permanent."

Figure 1: Unreinforced pipe fitting tests

Figure 2: Reinforced pipe fitting tests

Are Composite Materials Limited To The Repair Of Straight Pipes?

With the development and wide-spread use of wet lay-up composites, including field-impregnated as well as pre-preg systems (i.e., fibers pre-impregnated with resin and delivered in a sealed package), the range of piping geometries that can be repaired has increased significantly. As with all composite repairs, the repair of non-straight geometries requires careful consideration including detailed design calculations supported by full-scale testing.

Figures 1 and 2 are photographs showing several unique applications of composite materials used to reinforce non-straight pipe fittings including elbows and tees. To assess the performance of these repairs, tests were conducted on pipe samples in the reinforced and unreinforced conditions, which permitted a direct comparison to ensure that the composite repair system is actually performing as intended. The authors are aware of numerous studies in the past that failed to include tests of samples in the unrepaired state, leaving one to question the real benefit of the repair.

What Types Of Tests Are Required To Evaluate A Composite Repair System?

The required tests outlined in ASME PCC-2 and ISO 24817 composite repair standards are ideal places to start when outlining the basic framework for evaluating a composite repair system. However, over the past 10 years, Stress Engineering has performed additional tests that provide important insights into how a repair system performs when subjected to actual operating conditions. We believe that, before any system is used to repair high pressure pipeline and piping systems, two additional tests should be conducted that are currently not required in the existing repair standards. These are discussed below, along with supporting test results.

Burst Test Of Corroded Pipe With Strain Gages Used To Measure Inter-layer Strains

When designing a composite repair system, the issue of design stress of the composite repair material is critical from a long-term performance standpoint. While most composite manufacturers have a design stress based on calculations and/or testing; few products have been tested to measure actual stresses in the

Figure 3: Machined corrosion with inter-layer strain gage installation

composite material at design pressures. For this reason, Stress Engineering encouraged several composite manufacturers to measure stresses in their system using strain gages installed between the layers during installation. Figure 3 shows photographs of the machined corrosion region and a strain gage being installed between layers. Figure 4 presents a plot of hoop stress as a function of radial position through the layers based on strain gage measurements. What is noteworthy in these data is that, even with the maximum measured stress of 9,438 psi, a safety factor of 7.6 exists for the short-term tensile strength of this particular material. Additionally, if one considers the average measured hoop stress in the system, an even larger safety factor of 11.3 is calculated. The key to ensuring the long-term integrity and performance of composite repair systems is to require that stresses in the composite material remain below the specified design stress. Testing, such as that described here, is a model for validating the repair's design; reminding us that we get what we inspect, not necessarily what we expect.

Pressure Cycle Testing of Corroded Pipe

Starting in 2007, Stress Engineering started conducting pressure cycle tests on composite materials used to repair 12.75-inch x 0.375-inch, Grade X42 pipe samples having 75% deep corrosion. The samples

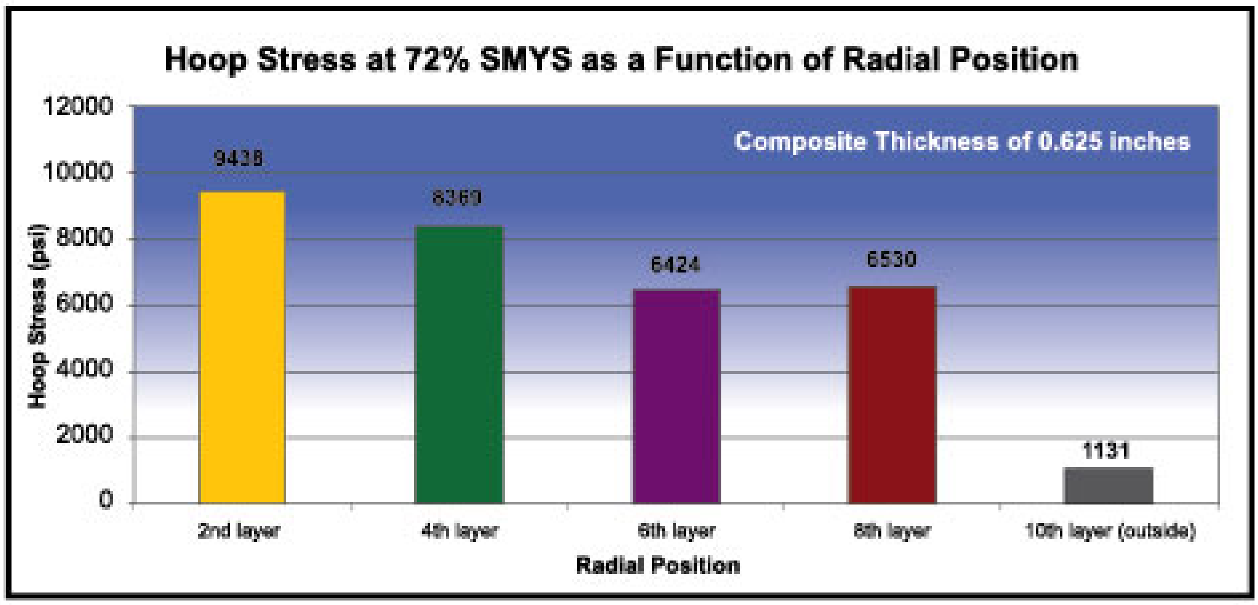

Figure 4: Composite stress based on strain gage measurements

were pressure cycled at 36% SMYS until failure. The original concept for this effort was to support our 10-year buried pipe study addressing the long-term performance of composite materials, However, this particular test has become in our minds a benchmark performance test for the current competing composite technologies.

Composite Repair Systems Tested

- E-glass system: 19,411 cycles to failure
- E-glass system: 32,848 cycles to failure
- E-glass system: 129,406 cycles to failure
- E-glass system: 140,164 cycles to failure
- E-glass system: 165,127 cycles to failure
- Carbon system (Pipe #1): 212,888 cycles to failure
- Carbon system (Pipe #2): 256,344 cycles to failure
- Carbon system (Pipe #3): 202,903 cycles to failure
- E-glass system: 259,537 cycles to failure
- Carbon system (Pipe #4): 532,776 cycles (run out, no failure)
- Hybrid steel/epoxy system: 655,749 cycles to failure
- Hybrid steel/E-glass urethane system: 767,816 cycles to failure

As can be seen, there is a wide range of performance in the data, clearly indicating that not all repair systems perform equally. These data reinforce the notion that full-scale performance testing is an essential element in any effort to qualify a repair system. Relying on material coupon testing alone is not sufficient. Additionally, we have observed that it is possible for composite materials to significantly extend the useful service life of damaged pipelines.

Can Composite Materials Reinforce More Than Just Corrosion?

While it is certainly true that the vast majority of repairs using composite materials involve the repair of corrosion, repairs are not limited to this particular type of anomaly. Other repairs include reinforcement of dents, mechanical damage, branch connections, and wrinkle bends. It should be noted that while the assessment of corrosion and the associated use of composite materials is relatively well understood, this is not necessarily true for other types of repairs. As a result, full-scale testing is always recommended before composite technology is actually deployed in the field.

One of the best examples from the past several years involved reinforcing branch connections using composite materials. The question was posed to Stress Engineering concerning the ability of composite material to reinforce branch connections not having sufficient steel reinforcement. In addition to pressure loading, all branch connections must be able to withstand in-plane and out-of-plane bending loads. To address this issue, Stress Engineering designed test fixtures to apply bending loads to branch connections. Figure 5 includes several schematics and photographs showing how the branch connections were tested. The program's results demonstrated that composite materials can be used to reinforce branch connections subjected to internal pressure, as well as in-plane and out-of-plane bending loads. Strain gages were also useful in quantifying the level of strain reduction in the branch connection itself to ensure the presence of adequate design margins.

Conclusion

Evaluating the performance of composite repair systems has been an important role in the services offered by Stress Engineering over the past two decades. We expect this trend to continue as we build on the existing body of knowledge. By properly designing and evaluating composite repair solutions using full-scale testing, the energy industry can proceed with confidence in repairing damaged pipelines and piping, thus ensuring a safer environment for the professionals in our industry and the public at large.

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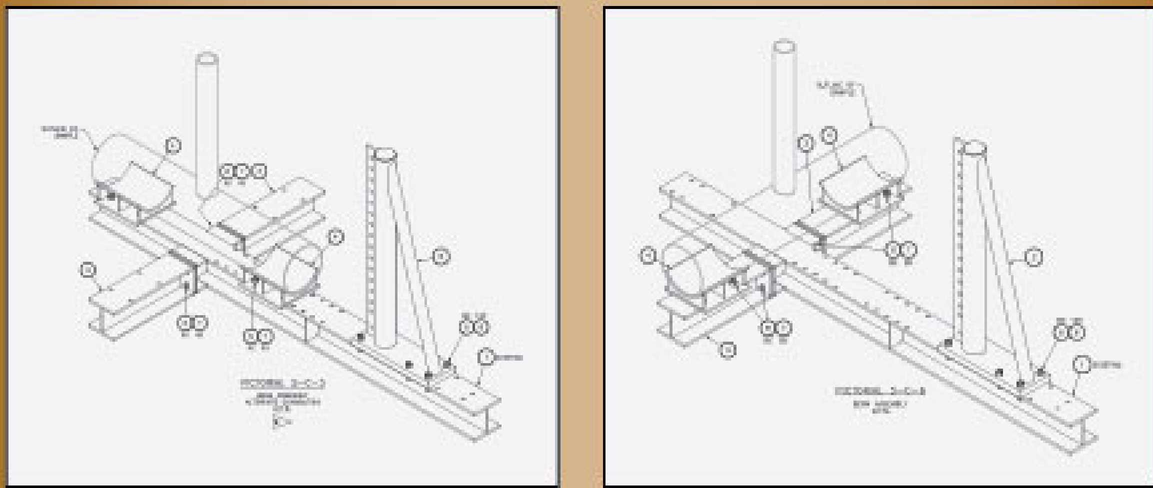


Diagrams showing set-up for in-plane (left) and out-of-of-plane (right) bending tests

Final displacements for unreinforced (left) and reinforced (right) in-plane bending tests

Unreinforced In-plane Sample (after 13.3 inches displacement at 88.6 kip-feet bending)

Reinforced In-plane Sample (after 4.7 inches displacement at 124.0 kip-feet bending)

Post-test sections showing results for the unreinforced and reinforced conditions

Figure 5: Diagrams and photographs for branch connection tests

Monitoring Real-Time Stresses
on Mining Equipment in the Alberta Oil Sands

Jeff Nicholls, P.E.

OVERVIEW

Stress Engineering Services Canada (SESC) was retained by a leading supplier of semi-portable oil sands processing equipment to monitor real-time strains and stresses during the relocation of three large pieces of ore preparation equipment at a mine site near Fort McMurray, Alberta.

STRAIN GAGE TECHNOLOGY

Resistance strain gage technology has existed since the 1930s and is still used today for a wide variety of applications. Since they measure the actual surface strain present in a material, these devices can be used to measure force on known cross-sections or strain directly. Applied force can be derived when the structural cross-section is known. This is the principle behind numerous load cell types. In strain measurement, the gages can identify how close a component is to yielding and, therefore, can also be used for safety monitoring.

Strain gages work on the basic principle that the electrical resistance of a wire changes as it is elastically lengthened or shortened. Strain gages are bonded to the component of interest so that they become an integral part of the component. The gage then experiences the same strain as the piece. Specialized electronic signal conditioners apply an excitation voltage to the gage and amplify the resulting low-level analog signal for recording the small changes in resistance that occur in the gage as a result of loading. Today's monitoring equipment can measure and record data at rates of up to 1 million readings per second, if required.

THE PROJECT

Oil sands ore requires specialized bulk handling and processing equipment to prepare it for the extraction of bitumen. Our client was supplying this equipment as part of an expansion of a surface mine operation. The

Surge Structure in Transit

SPMT Configuration/Roof Structure In Transit

significant size of this equipment required that it be assembled on site. Since the mine was in operation during the assembly process, it was beneficial from a scheduling standpoint to assemble the equipment on

For ease of installation in the cold temperatures (as low as -40°C at the time of installation), weldable single element strain gages were selected for this application. The gages were installed onto the structures using a portable, battery-powered capacitive discharge spot welder. Once installed, the gages were connected to a high-performance analog/digital signal conditioner and monitored on a laptop computer.

Strains were monitored for three major phases of the relocation: 1) jacking (lifting) of each piece of equipment off of the temporary construction foundations and setting the equipment onto the self-propelled modular transporter (SPMT) units, 2) moving the equipment down the heavy haul road from the assembly area to the ore preparation pit, and 3) lifting and placing the pieces onto their semi-permanent foundations.

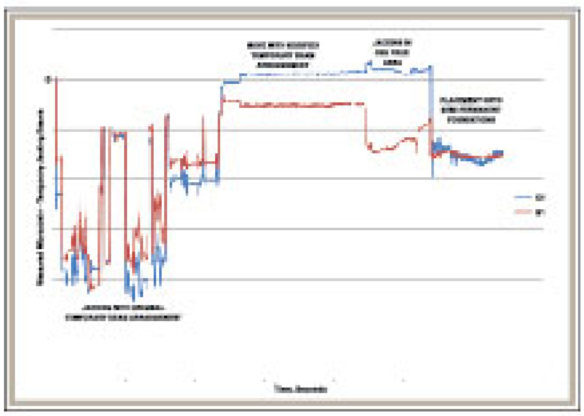
> Strain gages work on the basic principle that the electrical resistance of a wire changes as it is elastically lengthened or shortened.

temporary foundations and transport it approximately 1.5 kilometers to the permanent foundations in the ore preparation pit. Three separate pieces of equipment were strain-gaged and monitored during the relocation—the pumphouse roof structure, crushing plant, and surge plant. The surge plant was the largest and heaviest of the three structures. In total, 64 uniaxial strain gages were installed on these three components for this project.

The strain gage locations, which were specified by the equipment supplier's structural engineer, coincided with areas of the structures and temporary support/bracing members where the stresses during the relocation were anticipated to be the highest. At each specified location, single-element strain gages were installed and oriented in the direction of the anticipated primary stress.

The equipment was to be relocated during the winter months at a time when the haul roadbed would be frozen to maximize the bearing capacity of the road.

For the monitoring phase of the project, the client's structural engineer provided SESC a "redline" strain value that was not to be exceeded. During each phase of the move process, real-time monitoring of the strain gages provided immediate feedback for coordinating with the heavy-lift specialists. If the strains approached the maximum allowable, minor adjustments to could be made to the SPMT levels to reduce stresses in the structure.



Strain Plot for Temporary Beam Arrangement

As one piece was being jacked, strains in two of the temporary jacking beams rose to the maximum allowable. The trailer levels were adjusted, but a satisfactory reduction in strain in the jacking beams could not be achieved. Lifting of the unit was paused to prevent potential structural damage. The structural engineer reviewed the recorded strains up to that point. Analysis of the data revealed that the load onto the SPMT's at the temporary beam location was higher than initially anticipated. The jacking beam arrangement was modified using the loads calculated from the strain data. Strains in this area were then found to be satisfactory, and relocation of this component was completed safely.

SUMMARY

Strain gages were successfully used to monitor loads in the ore preparation equipment during their relocation. Real-time monitoring of the strain gages data during the relocation process provided continuous feedback and identified areas of higher than anticipated stress in one of the pieces of equipment. Modification of the design of the support structure using the strain gage data prevented structural damage to the equipment.

Strain gage technology is an effective tool for measuring loads in equipment and structures, and can be used in a wide variety of different situations and operating environments. Stress Engineering installs over 5000 strain gages every year to assist our clients in solving their toughest problems. We also provide complementary custom-designed data acquisition systems capable of real-time and remote monitoring.

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Hoisting and Placement of Roof Structure

StrainDAQ® version 11 Software Released

Stress Engineering Services, Inc. (SES) Measurement and Controls Division continues to upgrade and improve its premiere field and laboratory data collection software, StrainDAQ. StrainDAQ has been the main software package used by SES for both laboratory and field testing, as well as by many of our clients around the world. This past year, SES released StrainDAQ version 11, which provides many additional features and modifications to the already powerful software tool.

Additional Features and Improvements:

- Windows 7 support
- 64-bit system support
- Stream-lined setup, logging and calibration screens
- Screen menus reduce window clutter
- Higher scan/logging rate capabilities
- New hardware driver integration
- Additional DAQ hardware options including USB and Ethernet devices
- Integration of SES Turbo software functions (optional)
- Summary file generation and plotter

The central goal for this upgrade and revision of StrainDAQ was to retain many of the basic set-up features while optimizing the set-up and logging features. This approach will minimize retraining issues for current and previous users of the software. The software still includes many of the popular features of earlier versions, such as the data table, graphing windows, and rosette and pipe bending calculations.

Version 11 has been commercially available for several months; upgrade options are also available for existing users.

Pipeline Lateral Buckling Analyses

Rafik Boubenider, Ph.D., P.E.

Spurred by the current demand for energy and recent advances in technology, reservoirs previously considered as cost-prohibitive are now being reconsidered for development. As world energy demands increase, additional oil and gas prospects are being exploited in deep and ultra-deep water depths, where the reservoirs have high pressures and high temperatures. Exploitation and production of oil from these High-Pressure / High-Temperature (HPHT) reservoirs demand special considerations for the design of pipelines. The flowline's high-temperature operating conditions result in real challenges in designing and selecting materials for the pipeline system. Different failure modes must be investigated, and the resulting axial loads can result in lateral buckling of the flowlines.

Stress Engineering Services has significant experience in modeling pipelines on the seafloor to predict their lateral response under the normal operating conditions of HTHP. We can incorporate the seafloor bathymetry of the flowline, route of the flowline, and axial and lateral friction coefficients between the flowline and seafloor (Figures 1 and 2). Methods to mitigate lateral buckling can be incorporated in the model, such as the use of sleepers or buoyancy.

Under HPHT conditions, the pipeline undergoes significant axial expansions due to both pressure and temperature effects. There are five principal factors affecting axial expansion of a pipeline:

1. **Axial expansion of the pipeline due to the thermal gradients**
2. **Axial expansion of the pipeline due to internal pressures**
3. **The length of the pipeline**
4. **Submerged weight of the pipeline**
5. **The soil's axial friction coefficient**

The length, submerged weight of the pipeline, and axial resistance of the soil counterbalance the effects of internal pressure and thermal expansion. Axial resistance of the soil friction will result in compression along the pipeline, which potentially could result in a buckle (Figure 3).

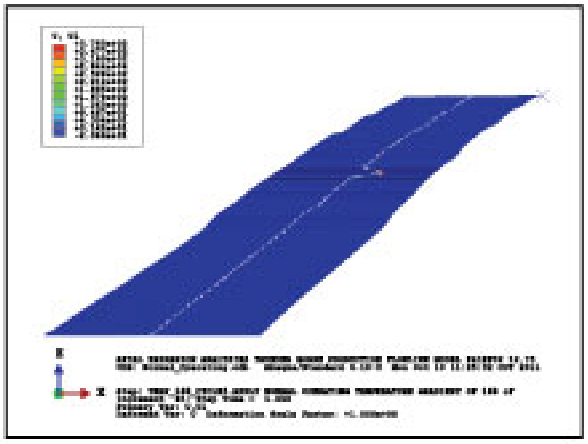

Figure 1: Buckled shape along an HPHT pipeline

Further considerations of high-stress, low-cycle fatigue damage need to be assessed for HPHT flowlines throughout their service lives. Typically, a flowline undergoes shut-in and start-up cycles during its service life, with significant temperature and pressure variations. These variations could generate significantly high stress ranges in the crown of the buckle of the flowline, thus severely impacting its safety and integrity. Figure 4 shows the bending moment distribution along an HPHT pipeline. One can see that there is a significant bending moment response in the region of the pipeline where a buckle has formed.

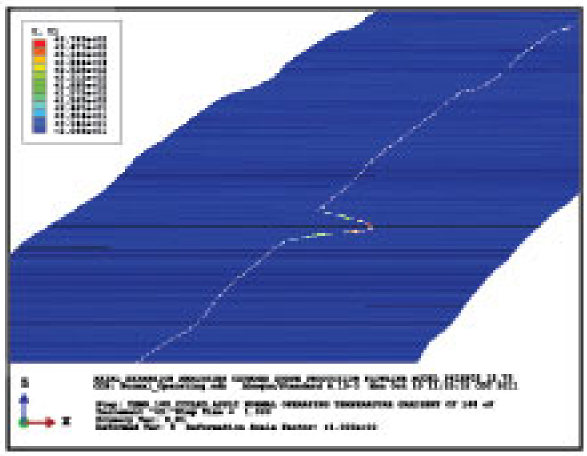

Figure 2: Close-up on the buckled shape along an HPHT pipeline

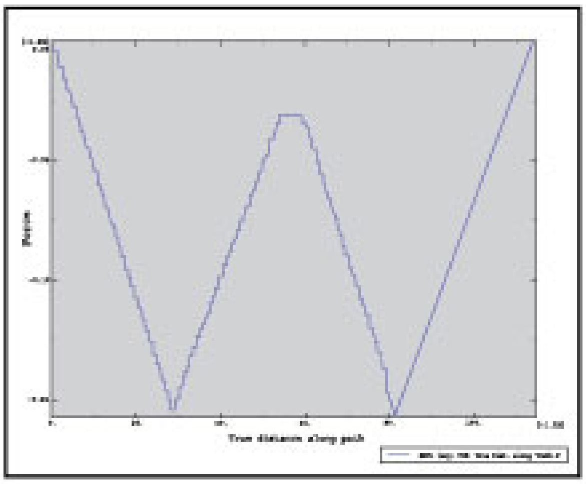

Figure 3: Effective Tension distribution along an HPHT pipeline

The stress response of a flowline under variations in pressure and temperature is highly nonlinear and path-dependent. Stress Engineering Services can help you generate the flowline's stress histograms for temperature and pressure variations. These stress histograms can be used to determine the maximum allowable initial flaw sizes in the welds along the flowline using the fracture mechanics approach through Engineering Criticality Assessments (ECA) during the design phase of the pipeline. They can also be used to establish the safety and integrity of the flowline, if existing flaws have been identified through routine inspections.

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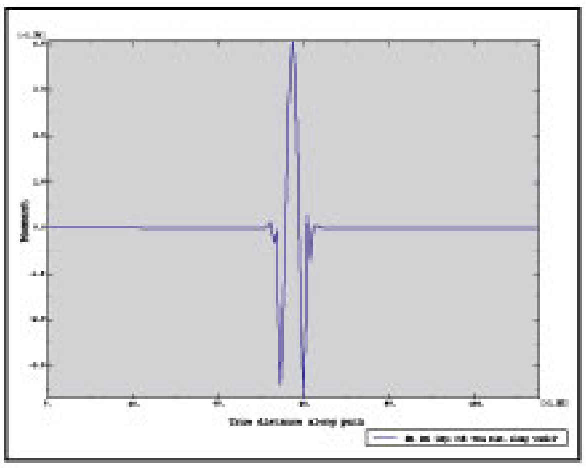
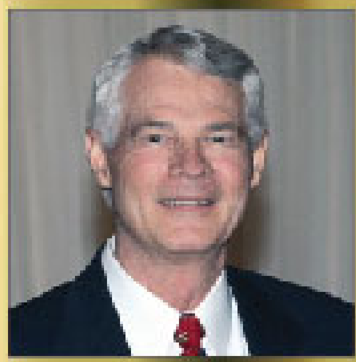


Figure 4: Bending moment distribution along an HPHT pipeline



In Memory of

Tom Asbill, P.E.

1942 - 2011

In October of 2011, the Stress Engineering Services family lost a beloved colleague and friend.

Tom joined Stress Engineering Services, Inc. in 1974. For over 37 years he served as Senior Vice President and Principal over Stress's Houston test lab operation.

Tom received his BS and MS in Mechanical Engineering from Texas A&M University. He won many awards for his professional work from Stress, API, and ASME. He was an internationally recognized expert on threaded tubular connections used for casing, tubing, and drill pipe for the oil/gas industry. Tom was the driving force behind the expansion and development of Stress's test labs into the most respected third-party testing operation in the world. His passion for delivering correct and timely results to customers led to significant business success for Stress Engineering and safer products and operations for our clients.

He was a man of integrity, honesty, charity and compassion. Tom's dedication and selfless nature was something that many could only hope to attain, and all who knew him regarded him with great respect and admiration.

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