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Engineering Analysis of Suitability for Pressure Vessel Re-Rating

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ABSTRACT

Though vessels, such as deaerators, are designed and operated for specific pressure and temperature conditions, oftentimes, a need arises to later increase or decrease the capacity necessitating re-rating. This article discusses the several engineering analyses, which are necessary for compliance with requirements of the National Board Inspection Code, and presents a case history where a successful re-rating of a deaerator was accomplished.

INTRODUCTION

Pressure vessels, such as deaerators, which are designed with safety factors for specific operating pressures and temperatures often are placed into service below the actual vessel limits. Use of standard material thickness may also result in higher actual operating limits than required. In the same instance, a need arises to later increase the capacity necessitating re-rating. Several engineering analyses and examinations are thus necessary to establish compliance with the requirements of the National Board Inspection Code.

The National Board Inspection Code outlines the criteria for re-rating of pressure vessels. Calculations must first be performed based on the actual dimensional and wall thickness data, material specifications, and property data which may be followed by more extensive analyses. Once the determination has been made as to the feasibility of re-rating a pressure vessel, a condition assessment is then performed. This involves utilizing various nondestructive examination techniques to assess the current integrity of the vessel in question, which may include hardness testing, on-site metallurgical examination for microstructural analysis, utilization of various nondestructive examination techniques to detect surface and subsurface defects or flaws, and possibly a variety of other techniques. Also important is hydrostatic testing to final design criteria, and possibly the performance of burst tests. The maximum allowable working pressure for vessels or vessel parts for which the strength cannot be computed with satisfactory assurance of accuracy is established using a proof test based on the bursting of the part.

Once the adequacy of a vessel for re-rating is determined and the hydrostatic pressure test has been witnessed and accepted by an Authorized Inspector, the necessary National Board approvals can be obtained. The cost benefits are clearly evident, leading to an increase in productivity, profitability, and assist in maintaining a competitive edge.

ENGINEERING ANALYSIS

Chapter 3, Section R-503 of the National Board Inspection Code outlines the procedures for re-rating a boiler or pressure vessel. Re-rating a pressure vessel by increasing the maximum allowable working pressure (MAWP) (internal and external) or temperature, is considered an alteration. To be performed successfully, the following criteria must be met:

1. Performance of calculations verifying the acceptability of the vessel for operation at the increased pressure or temperature by a registered professional engineer or the holder of a valid ASME Certificate of Authorization for use of a Code symbol stamp.

2. Re-ratings shall be done in accordance with the requirements of the applicable ASME Code.

3. Verification by review of current inspection records that the vessel is satisfactory for the proposed service.

4. Vessel has passed a pressure test for the intended service.

5. Vessel re-rating is acceptable to the Authorized Inspector (AI).

The successful re-rating of a deaerator from 75 psi pressure at 425°F temperature to 100 psi pressure at 425°F temperature is herein illustrated. The various steps undertaken to achieve this are outlined, and the accompanying calculations and forms are illustrated.

The drawing presented as Fig. 1 illustrates the geometric configuration of this pressure vessel, and the associated connections, and attachments.

The maximum allowable working pressure (MAWP), based on design criteria provided on the manufacturer's product drawing, was first calculated. Using the formula in Paragraph UG-27 of Section VIII Division 1, Rules for Construction of Pressure Vessels of the ASME Code, the MAWP for the deaerator fabricated from carbon steel material was determined to be 148.7 psi. The deaerator, therefore, passed the first step in the assessment process.

Initially, a condition assessment of the vessel was done. This included a detailed visual examination, to detect evidence of cracking, pitting, corrosion, or other conditions which might affect the operational suitability of the vessel. External examinations were also performed, to identify areas of inadequate support, damaged insulation, etc.

The weld integrity was established by using the wet fluorescent magnetic particle examination technique. Due to deaerator weld failures, TAPPI and NACE have made recommendations for safety incorporated in design, construction, and operation. The NBBI Committee, NACE, and TAPPI have all stated that the most suitable method for establishing weld integrity in deaerators is the wet fluorescent magnetic particle examination technique. This highly sensitive procedure is used to detect defects on the surface of the vessel. A typical condition which was found during the examination is illustrated in Fig. 2. Any areas of rejectable indications, which would have been found, were to be identified for subsequent repairs by welding. This would become necessary in order to successfully complete the re-rating. However, as a result of the visual and nondestructive examinations performed on the selected areas within the deaerator, repairs were not required to be performed. The indication was removed by slight grinding.

Hardness testing was then done using a portable hardness tester. The values obtained were then converted to equivalent tensile strength values, to confirm the adequacy of the allowable stress used in the calculations. Data provided in Table I confirmed that the mechanical properties of the carbon steel used in the construction of the deaerator were in excess of the specified values; therefore, the specified minimum allowable stresses which were used in the calculations were considered acceptable.

Furthermore, dimensional data including diameter and wall thick-ness measurements of the shell, heads, nozzles, and outlets were obtained. Wall thickness measurements were taken at randomly selected locations, Table II. Based on the specified wall thickness values which were lower than the values obtained, the reinforcement requirements at the outlets and nozzles were calculated. The maximum allowable working pressure was then re-calculated, and determined to be 107.7 psi. This confirmed the vessel suitability for re-rating at the intended operating pressure of 100 psi at 425°F temperature.

Since the joint efficiency of the welded vessel depends on the type of the joint and the degree of the examination, the degree of radiographic examination could effect the calculated maximum allowable working pressure. For example, a welded joint, which has been subjected to spot radiography, will have a joint efficiency factor E = 0.85; whereas, the same welded joint, if subjected to full radiographic examination, will have a joint efficiency factor E = 1. Consequently, a 15% increase in MAWP could be realized if the welded joints on a deaerator, which were originally subjected to spot radiography, are fully radiographed.

A Finite Element Analysis (FEA) would have been required if it was necessary to show the stress distribution of the vessel between the head and the shell. A typical profile of stress contours of a cylindrical shell subjected to internal pressure is shown in Fig. 3. Although not used for this project, FEA has been a useful tool for other pressure vessel re-ratings.

A hydrostatic pressure test was also performed. The vessel was pressurized with a pump, and the pressure was increased at 30 psi increments to 150 psi (one and a half times the MAWP). The pressure was measured by two dial indicator pressure gauges located approximately even with the upper hemispherical head to shell tank girth weld. The pressure was maintained for 30 minutes at 150 psi, to allow examination of the vessel, to detect visible leakage at all joints and connections. Visible leakage was not found, and the pressure readings did not show a pressure drop.

Indications requiring repair were not evident. However, if the hydrostatic pressure had revealed any leakage at the welded joints or nozzle connections, a repair welding procedure would have been prepared for correction of the problem.

The R-1 Form, Fig. 4, was then completed. The results of the calculations, the condition assessment, and the hydrostatic testing confirmed that the vessel was suitable for re-rating from 75 psi to 100 psi, operating pressure at 425°F temperature. It also complied with the requirements of the National Board Inspection Code.

CONCLUSION

Based on the acceptable results of the program, the re-rating of the vessel from 75 psi to 100 psi working steam pressure at the 425°F temperature was reviewed by the Authorized Inspector. The completed R-1 form was then accepted, and the certificates were issued under the Thielsch Engineering Associates R Stamp.

LITERATURE CITATIONS

National Board Boiler Inspection Code, 1989 Edition, NB-23, Rev. 7

ASME, Section 8, Division 1, Rules for Construction of Pressure Vessels

Thielsch Engineering Associates Report No. 4635, January 23, 1991.

TABLE I

Hardness Readings, Estimated Equivalent Tensile Strengths and Allowable Stress Values

	HARDNESS - VHN	TENSILE STRENGTH	ALLOWABLE STRESS PSI
Shell Location A			
1	117.0	57.0	
2	121.0	59.0	
3	120.0	58.5	
Average	119.0	58.2	14,625
Shell Location B			
1	122.0	59.5	
2	125.0	61.0	
3	119.0	58.0	
Average	122.0	59.5	14,875
Shell Location C			
1	127.0	62.0	
2	123.0	60.0	
3	120.0	58.5	
Average	123.0	60.2	15,050
Head - Bottom			
1	122.0	59.5	
2	122.0	59.5	
3	125.0	61.0	
Average	123.0	60.0	15,000
Head - Top			
1	123.0	60.0	
2	127.0	62.0	
3	124.0	60.5	
Average	124.7	60.8	15,200
Nozzle			
1	140.0	67.5	
2	132.0	64.0	
3	143.0	68.5	
Average	138.3	66.7	16,675

TABLE II

Wall Thickness Measurements

	SPECIFIED	ACTUAL
SHELL	11/16" (0.69")	0.771" MAX.
		0.716" MIN.
HEADS	13/16" (0.81")	0.886" MAX.
		0.827" MIN.
NOZZLE	3/8" (0.38")	0.391" MAX.
		0.381" MIN.

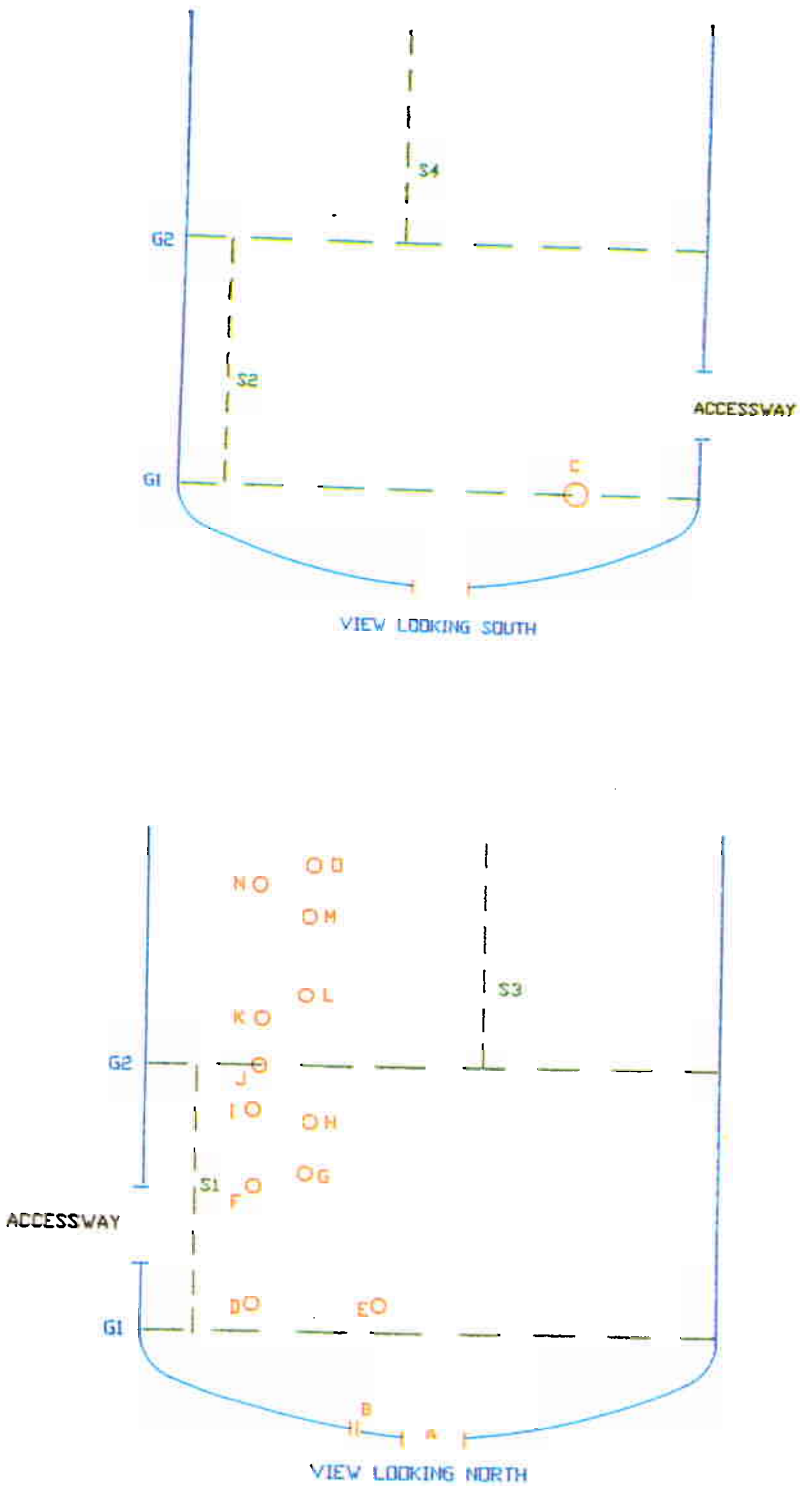

Fig. 1. Partial drawings of deaerator showing examination locations.

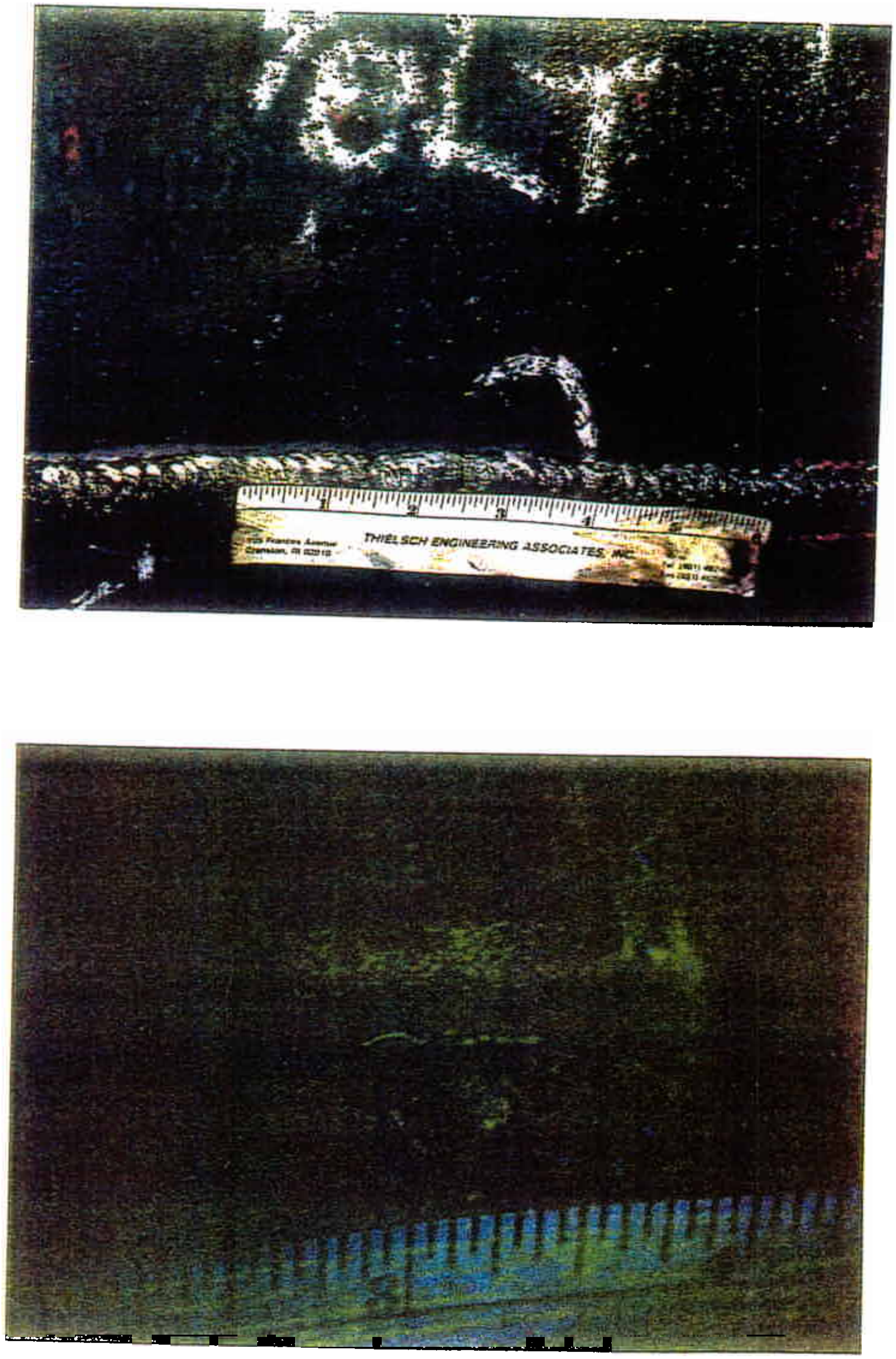

Fig. 2. Typical indications found with nondestructive examination.

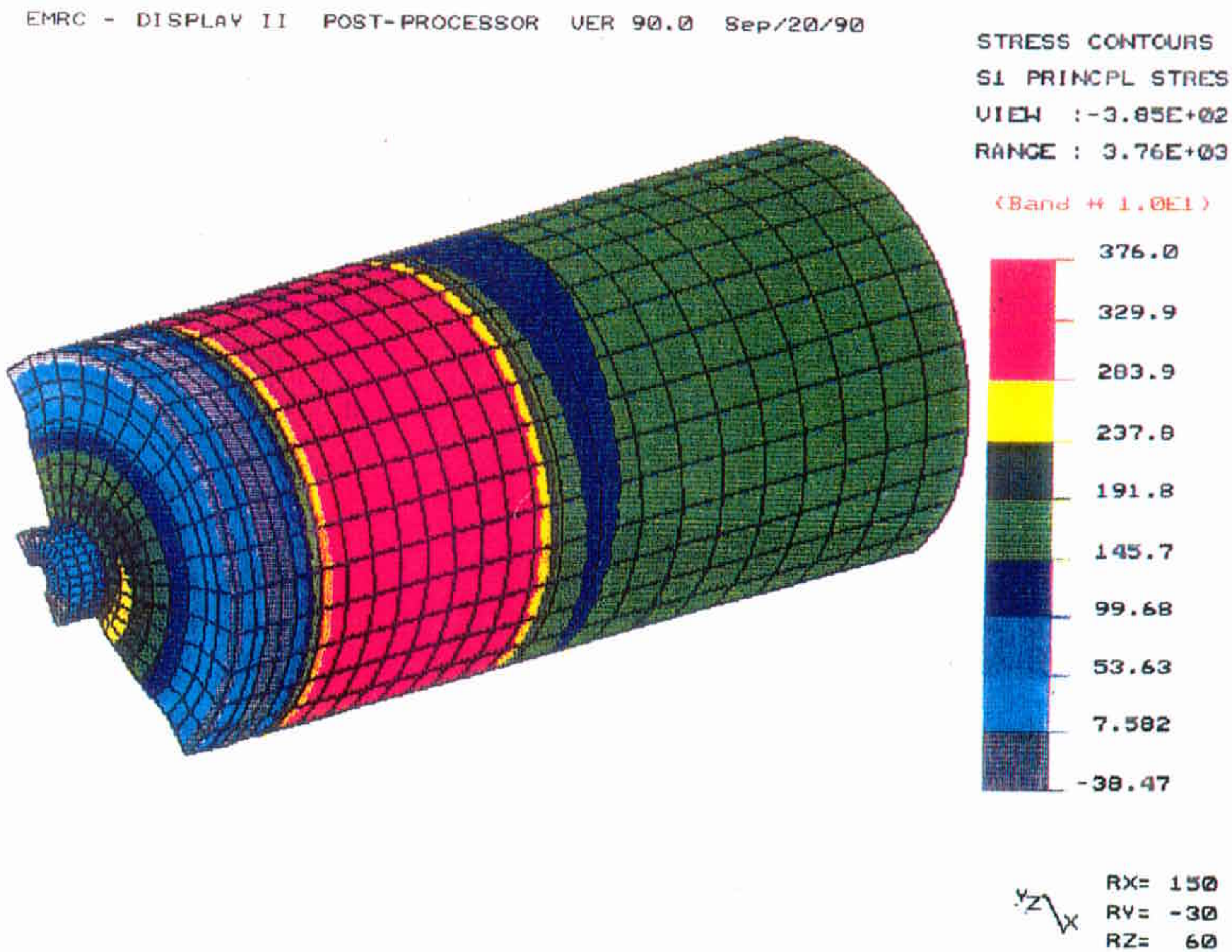

Fig. 3. Stress contour profile for cylindrical shell subjected to internal pressure.

FIGURE 4 — FORM R-1, REPORT OF WELDED ☐ REPAIR OR ☐ ALTERATION ①
as required by the provisions of the National Board Inspection Code

1. Work performed by ________ ② ________ ________ ③ ________
(name of repair or alteration organization) (P.O. no., job no., etc.)

____
(address)

2. Owner ________ ④ ________
(name)

____
(address)

3. Location of installation ________ ⑤ ________
(name)

____
(address)

4. Unit identification: ____ ⑥ ____ Name of original manufacturer ________ ⑦ ________
(boiler, pressure vessel)

5. Identifying nos.: ____ ⑧ ____ ____ ⑨ ____ ____ ⑨ ____ ____ ⑨ ____ ____ ⑩ ____
(mfr's. serial no.) (original National Board no.) (jurisdiction no.) (other) (year built)

6. Description of work: ________ ⑪ ________
(use back, separate sheet, or sketch if necessary)

____

____ Pressure test, if applied ____ ⑫ ____ psi

7. Replacement Parts. Attached are Manufacturers' Partial Data Reports properly identified and signed by Authorized Inspectors for the following items of this report:

________ ⑬ ________

____
(name of part, item number, mfr's. name and identifying stamp)

8. Remarks: ________ ⑭ ________

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