Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997

K13/2

The US NRC seismic analysis of piping research program

Chokshi N.C.[(1)]**, Shao L.C.**[(1)]**, Jaquay K.R.**[(2)]
(1) U.S. Nuclear Regulatory Commission, USA
(2) Boeing North American, Inc., USA

ABSTRACT: This paper describes the U.S. Nuclear Regulatory Commission (NRC) Seismic Analysis of Piping research program being conducted at the Energy Technology Engineering Center (ETEC) to assist the NRC in reviewing and assessing the technical bases for the ASME Code seismic design criteria for nuclear plant piping as revised by the rule changes in the Code 1994 Addenda. This paper also provides background on the rule changes, summarizes the review findings and presents test-based minimum seismic fatigue margins.

1 DEDICATION AND ACKNOWLEDGMENT

This paper is dedicated to the memory of Dr. Wellington Paul Chen, the ETEC principal investigator and program manager of the Seismic Analysis of Piping research program and original lead author of this paper. Dr. Chen planned and directed all the research reported in this paper and much of the text is extracted from the NUREG program summary report that he was writing at the time of his tragic death. Paul will be greatly missed.

2 BACKGROUND

The ASME Boiler and Pressure Vessel Code Section III (Code) seismic design rules for nuclear plant piping were significantly revised by the Code 1994 Addenda. The Level D Service Limits on linear elastically calculated limit load stresses (values based on limit load indices) due to combined pressure, weight and seismic inertial loadings were conditionally increased by 50% to over 100% depending on Safety Class, material and temperature. Ten conditions, easily met in practical designs, are required to be met to use the higher service limits. These are (1) the material must be a ferrous alloy listed in the Code material tables as P-No. 1 to P-No. 9, (2) the outside diameter to wall thickness ratio must not exceed 50, (3) the internal pressure must not exceed the Design Pressure, (4) the weight-induced limit moment stress must not exceed $0.5S_m$ (S_m is the Code Class 1 allowable stress intensity value), (5) the seismic inertial moment loading must be computed per a specific Code methodology using 5% damping and not less than $\pm 15\%$ spectrum peak broadening, (6) the seismic anchor motion (SAM) secondary moment stress range must not exceed $6S_m$, (7) the

* The views expressed in this paper are those of the authors and should not be construed to reflect the NRC position.

section-averaged SAM axial stress must not exceed S_m, (8) the seismic inertial displacements must satisfy Design Specification limits, (9) the frequency ratio R_w (ratio of the predominant frequency of the input loading to the system fundamental frequency) must be at least 0.5 and (10) the number of non-seismic reversing dynamic loads must be less than 20.

An alternate set of criteria requiring dynamic time history inelastic piping analyses is also provided that limits accumulated wall-averaged effective strains to 5% and places a 10 cycle based fatigue limit on effective peak strain ranges.

The revised rules are the culmination of almost fifteen years of industry and NRC efforts which were initiated in response to reviews of piping seismic design criteria begun in the early 1980's by the NRC and the Pressure Vessel Research Council (PVRC). These reviews resulted in the joint Electric Power Research Institute (EPRI)/NRC Piping & Fitting Dynamic Reliability (PFDR) program[1] implemented by the General Electric Company (GE) which included simulated seismic tests on 33 simple cantilever configurations of piping components conducted at ANCO Engineers, Inc. (ANCO), simulated seismic tests on 2 prototypic piping systems conducted at ETEC, fatigue-ratchet tests conducted at the Materials Testing Characterization Laboratory, and GE developments of proposed Code rule revisions.

Subsequently, a number of rule changes were proposed to the Code rule committees and considered by an informal task group to the ASME Working Group on Piping Design (WGPD). In 1991, the ASME Subgroup on Design (SGD) formed a Special Task Group on Integrated Piping Criteria (STGIPC) to develop an integrated strategy for considering the numerous rule proposals. Concurrently, the Advanced Reactor Corporation (ARC) was assessing margins in the current design rules and developing revised rules through its Technical Core Group (TCG) for advanced light water reactor (ALWR) designs. The TCG margin assessments and revised rules were discussed in the STGIPC meetings. The TCG was proposing rules similar to, but not exactly the same as, those proposed earlier by GE and those eventually published in the 1994 Code Addenda.

In April 1993, a TCG report[2] and a preliminary STGIPC report[3] were issued, and together were intended to provide the technical bases for revising the piping seismic design rules. Although the STGIPC report was supported by a majority of the task group, it was opposed by a minority including the two NRC representatives. The technical concerns forming the bases for the minority position were documented in the STGIPC report. Some of the concerns identified by the minority members were evaluated by the TCG and documented in both the TCG and STGIPC reports. However, the correctness of the evaluations and the significance of the results were controversial.

The Main committee passed the new rules in February 1994. In May 1995, the NRC informed the ASME[4] that additional effort is necessary to provide the technical basis the staff requires to endorse the new rules. A willingness was expressed to articulate the staff concerns and develop a course of action that leads to resolution of these concerns.

In September 1995, the SGD formed a Special Working Group on Seismic Rules (SWG-SR) to address concerns on the technical bases for the new rules. There are two NRC observers and one ETEC observer assigned to the SWG-SR. Currently, 15 prioritized categories of technical issues have been identified.

3 ETEC PROGRAM OVERVIEW

In June 1993, ETEC was contracted by the NRC-RES to provide technical assistance to the NRC staff in assessing the technical bases for the proposed revisions to the piping seismic design rules and for other industry and NRC initiatives in the piping seismic design area. An informal ETEC program Peer Review Group (PRG) of W. Iwan, E. Rodabaugh, E. Wais and L. Shipley, and later G. Wilkowski and R. Kennedy, was created by ETEC to review findings of the ETEC studies and provide program technical oversight. PRG participants were also contracted to conduct special program research studies.

The ETEC program reviews of the technical bases for the new rules were based on the GE PFDR semi-annual reports[5], earlier drafts of the EPRI PFDR reports, the ANCO "Quick Look" component test reports, the TCG report and the STGIPC report, supplemented by a collection of ASME rule committee correspondence and presentation packages. The ETEC program reviews identified 11 general issues discussed later, 5 specific rule issues and a concern that margins can be well below 1.0 based on an ETEC margin study discussed later.

In 1993, ETEC conducted a literature survey of piping seismic criteria and tests, and categorized over 450 documents by content in a computer data base. In 1994, an information gathering trip to Germany, France and the UK was taken to acquire information on overseas seismic research. A similar trip to Japan has been planned and open literature exchanges on piping seismic design criteria have been made.

Piping component seismic fatigue margin assessments were conducted by ETEC using test data from both the ANCO Quick Look test reports and a collection of open and proprietary Central Electric Generating Board (CEGB) reports on dynamic sinusoidal component tests conducted at the Berkeley National Laboratories (the "Beaney tests").

"Seismic fatigue margin" refers to the input-acceleration-based factor of safety on pressure boundary failure by through-wall cracking in one seismic event. The use of acceleration based ratios is questioned later in this paper. The cracking is often accompanied by diametrical growth ("pressure bulging"), termed "ratchet-fatigue", and/or accompanied by inelastic rotations. In this paper, seismic margins against through-wall cracking, when correlated by a standard fatigue curve are simplistically termed "seismic fatigue margins", and are identical in principle to the GE and TCG margins.

The same pressure boundary failures are also being correlated by the ratio of rotation to the maximum rotation during all the test runs in what is termed a "ductility margin". This is a test-demonstrated lower bound margin and the actual margin against through-wall cracking is expected to lie somewhere between the fatigue margin and the ductility margin.

"Collapse" is another rotation related failure mode discussed in this paper, whose occurrence in the PFDR component tests is a debated issue and for which margins have yet to be calculated. In this paper, "collapse" refers to the inability of a component's internal stress state to further resist an external moment loading, and large unbounded rotations will occur under continued application of the loading, i.e., a "plastic hinge" has formed.

A fatigue failure correlation study was conducted by ETEC for the PFDR component tests using both Code Class 1 (K_e-adjusted "C_2K_2") and Code Class 2/3 (Markl) stress based fatigue damage models. The test fatigue failure data scatter could be significantly reduced using these "peak stresses" versus the new rule usage of limit load stresses.

A verification study was conducted by ETEC of the Structural Mechanics Analysis Inc. computer program REMSFATI used by the TCG to study frequency ratio effects in PFDR component Test 36. Problems were encountered with the strain ranges being used.

C.T. Huang at California Institute of Technology (CIT), under the direction of W. Iwan, was contracted to develop a closed-form equation-of-motion based analytical technique for duplicating the hysteretic behavior of the PFDR component tests and extrapolating test seismic margins to untested configurations and loadings. E. Wais assisted in the definition of various cycle count methodologies and fatigue damage models used in the study. ANCO provided test data computer files and ETEC developed time histories of alternate earthquakes. Analysis techniques and alternate extrapolation approaches are presented in a sister SMiRT 14 paper[6], and a ductility margin is proposed in an ICOSSAR '97 paper[7].

The CIT study is focused on four PFDR component Tests 11, 14, 36 and 40. The study addresses the margin effects of different R_w values, earthquake time histories, temperatures, eccentric weight moments and α_w values. α_w, the P-Δ stiffness ratio, relates to the fraction of total restoring moment provided or resisted by gravity. Fatigue margins and ductility margins are being computed and presented in margin spectra as a function of R_w.

Figure 1 illustrates the two margin definitions and the effect of time histories on margins. Figure 2 illustrates the effect of eccentric weight moments on ductility margins.

One of the more interesting CIT study results, shown in Figure 3, indicates the presence of a regime of large deformation mechanisms for test systems with high R_w ratios and high P-Δ stiffness ratios. This refers to the sudden rise (steep cliff on plot) in the fatigue damage cumulative usage fraction (CUF) at higher level inputs. The CIT studies are providing insights into many of the NRC staff concerns and the results are being followed closely by the SWG-SR and other researchers of nonlinear seismic hysteretic response.

R. Kennedy was contracted to develop a technical basis for establishing appropriate seismic margin levels based on considerations of maintaining current seismic probabilistic risk assessment (PRA) evaluation methods. A sister SMiRT 14 paper[8] discusses this effort. The SWG-SR has used Kennedy's approach to establish an acceptable margin level of 2.0 on minimum test-based margin computed using nominal geometry and nominal material property assumptions. This assumes a sufficient data base exists to establish a 1% non-exceedance (NEP) capacity which is more test data than the PFDR component tests alone.

An ETEC concern with the impact of the new rules on flaw tolerance led to a program contracted study[9] by Batelle researchers Y. Zhao and G. Wilkowski that concluded that when flaws in piping at the new stress limits are larger than the Code acceptable workmanship standard flaws, the existing Section XI pipe flaw evaluation rules for justification of continued operation can not be used. Hence, the pipe would need to be repaired or replaced unless a new evaluation methodology based on nonlinear corrections to the elastically calculated stresses is developed. The implications for degraded piping were not considered in the ETEC review, but are not promising.

Finally, the ETEC program is continuing to support the SWG-SR activities by regular ETEC attendance and participation at the meetings and by reporting the results of ongoing CIT evaluations of specific SWG-SR issues. On occasion, ETEC is asked to provide data reductions of information contained in the ANCO test reports and data files.

4 ETEC REVIEW GENERAL ISSUES

The following are the 11 general issues that ETEC and the PRG had identified in the 1993-1994 reviews of the technical bases for the new rules, annotated with recent information.

(1) Collapse Failure Mode. The technical bases for the new rules assume a fatigue-ratchet failure mode. It is claimed that collapse is not a realistic failure mode in piping systems under reversing dynamic loads. This claim is not supported by PFDR Test 37 and Test 40 which exhibited incipient incremental collapse. It also was not demonstrated that the use of test inputs having a large displacement at low frequencies would not have resulted in collapse. Further, the ongoing CIT studies indicates the presence of a large deformation response regime for large R_w and α_w ratios that may reduce collapse margins.

(2) Inelastic Analysis Criterion. Inadequate justification is provided for the specified strain and fatigue limits for inelastic analyses. The results of the PFDR materials testing provide some insights into ratchet-fatigue interaction, but the PFDR Vol. 4 report conclusions are not quantitatively tied to the test data. More importantly, the likelihood of dynamic inelastic piping analyses being used for piping design is negligible and therefore this criterion should be deleted to allow reviews to be focused on the elastic analysis based rules.

(3) Margin Basis. The GE, TCG and STGIPC evaluations are based on acceleration ratio (test/Code) margin. Acceleration is an inconclusive measure of adequacy in low frequency systems in which displacement response can be equally important. Seismic displacements in low frequency systems are important considering the significance of P-Δ effects on collapse, the possibility of piping system interactions and the need to limit eccentricity of loads on some in-line equipment. Further, the use of acceleration ratios in the margin definition loses accountability of the reality of the acceleration levels being studied.

(4) Acceptable Margin Level. There was inadequate technical basis offered for the "2.0 to 2.5" targeted load margin value in the STGIPC report. However, Kennedy's recent developments have helped the SWG-SR identify acceptable margin levels.

(5) Predicted Loads for Support Design. Available data indicate that linearly elastic response spectrum analysis using 5% damping can underpredict support loads. The STGIPC approved a rule package that required increasing elastically predicted support loads by 20%, however, during higher ASME rule committee approvals, the requirement was dropped.

(6) Limited Test Data. The PFDF component tests were conducted with the predominant frequency of the test input only slightly below the test system's fundamental frequency (i.e., R_w near 1.0). This permitted achieving near maximum response accelerations in the test systems. The CIT margin studies indicate that both fatigue margins and ductility margins for the PFDR simulated seismic inputs peak locally at R_w near 1.0. Critical off-resonance low margin tests were not conducted and are still needed to benchmark the CIT studies.

Only one time history was used in the PFDR tests, a specific reactor vessel nozzle response to the Taft Earthquake using 7% building damping. Other earthquakes and plant locations could pass through time histories with significantly different displacement, velocity or acceleration frequency content, and result in different fatigue and ductility margins.

Finally, only room temperature PFDR component tests were conducted. Temperature adjustments to fatigue margins based on changes in elastic modulus, yield strength and fatigue resistance are complicated by the nonlinear relationships between ratchet and fatigue mechanisms. Further, high temperature changes in other material behavior, such as dynamic strain aging, make such temperature adjustments questionable. The PFDR ratchet-fatigue studies did not provide temperature effect assessments adequate to address these issues.

(7) Empirical Basis for Rules. The simplified stress expressions in the new rules use limit load indices that do not account for differences in fatigue resistance between different piping components. This was done in part to minimize the impact of the rule changes on current piping computer analysis codes and design practices. This criteria approach does not directly address the "ratchet-fatigue" failure mode observed in the PFDR tests and is therefore empirical. This leads to differences in seismic fatigue margins for different components and relies on a number of limitations on loadings and applicability restrictions that may assure conservatism for the PFDR tests, but not necessarily for piping systems in general.

(8) Component versus System Behavior. The new rules are based largely on the PFDR component testing, whereas the PFDR system tests at ETEC were dismissed as confirmatory and no margins were presented. The issue is higher mode failures illustrated by the System Test 2 fatigue failure in second mode response. Specifically, the applicability conditions for the new rules place upper frequency limits on the fundamental mode to avoid collapse failures, however, this does not address collapse failures in higher modes.

(9) Concurrent SAM Loadings. The PFDR component test cantilever setup could not address the effect on margins of concurrent SAM loads. A Stevenson and Associates (S&A) Test 36 based SAM study[10] indicating only a 15% reduction in margin due to maximum allowed SAM moments is a specific case. The S&A study used a Square Root of the Sum of the Squares combination of the inertial and SAM moments. The combination of mainline inertial and SAM loadings on small branch lines can be algebraic. Second, the choice of

Test 36 predicates a B_2/C_2 stress indice ratio of 0.75. An ETEC study repeating the S&A study for a butt weld ($B_2/C_2 = 1.0$) with algebraic sum gave a reduction in margin of 43%.

(10) Evaluation of Code Acceptable Imperfections. The flaw tolerance of piping systems designed to the new rules may be significantly degraded and impact the plant operability adversely. The earlier discussed special case study by Batelle highlights the issue.

(11) Applicability Conditions. The reasons for most of the applicability conditions that must be met to use the new rules were generally understood, although the justifications for some of the specific limits chosen were lacking. The need for the SAM axial stress limit was questioned since moment stress limits indirectly provide control of axial stresses. Three additional needed exclusions from the use of the new rules were identified; fatigue prone connections such as socket welds and threaded pipe, nonlinear supports and buried piping.

5 MINIMUM FATIGUE MARGINS

The ETEC program has conducted two other margin studies, besides the ongoing CIT study, using the PFDR component test data. Results of one of these margin studies[11] have been published widely. That study focused on the extrapolation of GE calculated test margins to worst case "untested" conditions. Not accepting, but using the GE acceleration ratio based test margins as a starting point, it corrected margins for the effects of frequency ratio, temperature and the use by GE of broadened spectra in the test margin calculations. ETEC adjusted several of the GE test margins that questionably used B_2 stress indices for the pipe fittings despite failures occurring in the adjacent straight pipes. ETEC also used a value of $B_2 = 1.0$ for Test 36 as discussed below. ETEC refined over half of the GE event counts by using an event count procedure based on strain-related measured response levels.

The other margin study, reported herein, extends the previous margin study to obtain "minimum" fatigue margins for postulated "weak" test articles having nominal geometry and minimum yield properties. The measured pre-test thicknesses closest to the failure locations were used for Section Modulus calculations. The ratios of the mill test yield values to Code minimum yield values at the failure locations were used to adjust the fatigue margins. Test margins were also adjusted upward to include the coincident weight and pressure stresses.

Table 1 presents the study results. Two B_2 cases are given for Test 36. The effect on fatigue margin of using actual thickness versus nominal thickness can be seen by comparing (Column) A versus B, the effect of including the pressure and weight stresses is B versus D, the GE and ETEC event count differences result in E versus F and the margin reduction factors used for mill data yield greater than minimum Code yield are in J. The L-O-Q adjustments are the same as in Reference 11. The minimum fatigue margins are listed in S.

Test 11, Test 14 and Test 36 (with $B_2 = 1.0$) had the lowest fatigue margin. Test 11 is a Schedule 10 stainless tee loaded out-of-plane through the branch. The failure was on the tee side of the branch weld ($B_{2b} = 3.35$ was used). This was the only Schedule 10 non-elbow test and the low margin occurs despite use of the fitting B_2 value. This leads to a concern with the level of fatigue margins in untested Schedule 10 products having $B_2 = 1.0$.

Test 14, a Schedule 40 carbon steel tee loaded out-of-plane through the branch failed in the adjacent straight pipe ($B_2 = 1.0$ was used). Test 36 is a Schedule 40 carbon steel tee loaded in-plane through the run. The failure was on the tee side of the run weld opposite the branch. The appropriate B_2 value for this test is controversial (opinions vary from 1.0 to 2.52) due to the load path, failure location and weld details.

Table 1 indicates that at least 5 test setups could have had fatigue margins less than 1.0 had minimum geometry/material test articles been used and worst case test conditions run. It also confirms that the CIT study is appropriately addressing the lowest fatigue margin tests.

6 REFERENCES

1. EPRI 1994. *Piping and fitting dynamic reliability program.* TR-102792, Five volumes.
2. ARC 1993. *Technical core group report on FOAKE task E-1: ASME piping.*
3. STGIPC 1993. *Preliminary report for ASME SCIII, SGD.* ASME.
4. Sheron, B. to G.M. Eisenberg 1995. ASME Code revisions to the design rules for piping systems. Letter May 24, 1995. US NRC.
5. English, W.F. 1985-1988. *Piping and fitting dynamic reliability program semi-annual progress reports.* General Electric. NEC-31272, NEC-31364, NEC-31450,NEC-31542.
6. Huang, C.T., W.D. Iwan, K.R. Jaquay & N.C. Chokshi 1997. Analytical study of frequency effects on seismic fatigue margins. To be presented at *SMiRT 14*: Lyon France.
7. Iwan, W.D., C.T. Huang, K.R. Jaquay & N.C. Chokshi 1997. Seismic margins for nuclear power plant piping systems. To be presented at *ICOSSAR '97*: Kyoto Japan.
8. Kennedy, R.P. and N.C. Chokshi 1997. A technical basis for establishing seismic margins in nuclear plant piping. To be presented at *SMiRT 14*: Lyon France.
9. Zhao, Y. & G. Wilkowski 1996. A case study for assessment of consistency between ASME section III and XI rules. *Seismic Engineering - 1996*. 331-343. ASME PVP-Vol. 340.
10. Adams, T. to TCG members 1993. Effect of SAM on the ARC EPRI Criteria. Facsimile July 26, 1993. Stevenson & Associates. Attached to agenda 11/93 ASME WGPD meeting.
11. Chen, W.P., K.R. Jaquay, N.C. Chokshi & D. Terao 1995. An assessment of seismic margins in nuclear plant piping. 507-512. Vol. 3. *SMiRT 13*: Porto Alegre Brazil.

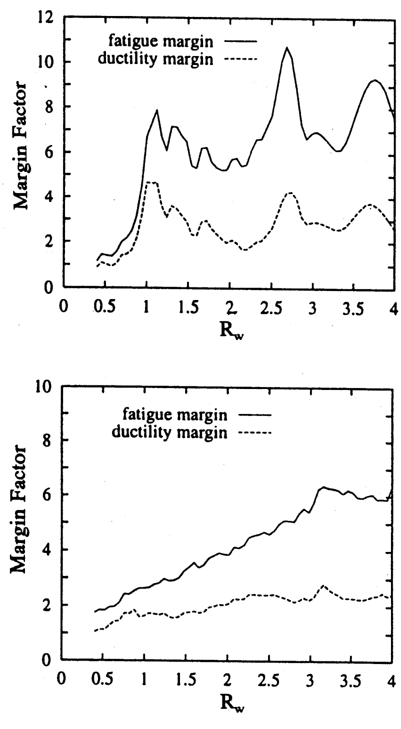

Fig. 1: Comparison of fatigue and ductility margin, $\alpha_w = 0\%$, Test 14 model, top: PFDR input, bottom: RG 1.60 input

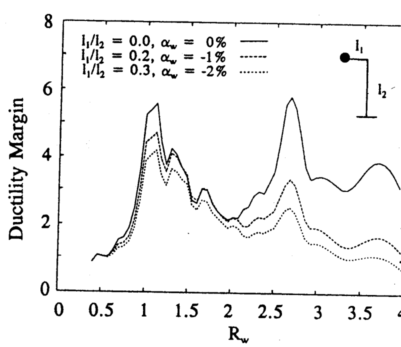

Fig. 2: Eccentric weight moment effects on ductility margin, PFDR input, Test 40 model

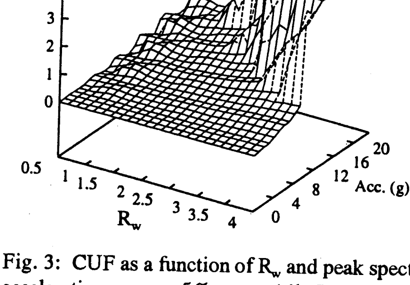

Fig. 3: CUF as a function of R_w and peak spectra acceleration, α_w = -5%, c_p = 1%, PFDR input, Test 36 model

Table 1: PFDR Component Test Minimum Fatigue Margins

	EQ 9 WITH THICKNESS ADJ						SINGLE EVENT ADJ							SY ADJ		TEMP ADJ		BRD RS ADJ			REMS RW ADJ		
COLUMN:	A	B		C	D		E	F		G	H	I		J	K	L	M	N	O	P	Q	R	S
TEST ID	B2M5 /Z NOM T	B2M5 /Z ACT T	INFO B/A	EQ 9 P,WT ACT T	EQ 9 TOT ACT T	INFO D/A	GE # OF EVNT	MM N/23	INFO F/E	EVNT CORR EQ 9	LOAD MRGN	TCG LOAD MRGN	INFO H/I	III/T SY	LOAD MRGN	650 F /70 F	LOAD MRGN	RW	UNBR /BR @RW	LOAD MRGN	MRF/ MRF@ 0.5	INFO O*Q	MIN FATIGUE MARGIN
ELBOW TESTS:																							
1	543	519	0.96	2	521	0.96	5.5	5.50	1.00	1222	13.58	14.00	0.97	0.88	11.95	0.82	9.80	0.833	0.51	5.00	0.66	0.34	3.30
2	498	474	0.95	1	475	0.95	9.5	9.50	1.00	1464	16.27	18.50	0.88	0.88	14.32	0.82	11.74	0.859	0.51	6.00	0.60	0.31	3.60
3	751	652	0.87	1	653	0.87	3.5	3.25	0.93	1177	13.08	15.70	0.83	0.88	11.51	0.76	8.75	0.900	0.62	5.42	0.53	0.33	2.87
4	644	595	0.92	0	595	0.92	2.5	2.60	1.04	959	10.66	11.40	0.94	0.73	7.78	0.82	6.38	0.806	0.51	3.25	0.73	0.37	2.38
5	670	631	0.94	0	631	0.94	3.5	2.50	0.71	998	11.09	15.70	0.71	0.73	8.10	0.82	6.64	0.900	0.62	4.12	0.53	0.33	2.18
6	630	575	0.91	0	575	0.91	3.5	3.30	0.94	1045	11.61	14.20	0.82	0.55	6.39	0.76	4.85	0.900	0.62	3.01	0.53	0.33	1.37
7	751	681	0.91	0	681	0.91	4.5	4.30	0.96	1412	15.69	19.50	0.80	0.55	8.63	0.76	6.56	0.714	0.51	3.34	0.87	0.44	2.91
13	679	482	0.71	1	483	0.71	2.5	4.41	1.76	1014	11.27	13.90	0.81	0.74	8.34	0.82	6.84	0.897	0.61	4.17	0.53	0.33	2.21
30	353	328	0.93	10	338	0.96	3.0	3.33	1.11	617	6.85	6.90	0.99	0.88	6.03	0.76	4.58	0.972	0.90	4.12	0.43	0.38	1.77
31	738	623	0.84	1	624	0.85	3.5	3.92	1.12	1235	13.73	17.20	0.80	0.78	10.71	0.76	8.14	0.875	0.53	4.31	0.57	0.30	2.46
35	645	601	0.93	7	608	0.94	5.0	4.58	0.92	1301	14.46	16.10	0.90	0.83	12.00	0.82	9.84	0.932	0.74	7.28	0.48	0.35	3.50
NON-ELBOW TESTS:																							
9(P)	330	342	1.04	11	353	1.07	1.5	1.50	1.00	432	4.80	10.30	0.47	0.59	2.84	0.76	2.16	0.900	0.62	1.34	0.53	0.33	0.71
10(P)	335	333	0.99	13	340	1.01	2.5	2.30	0.92	516	5.73	13.30	0.43	0.59	3.40	0.76	2.58	0.900	0.62	1.60	0.53	0.33	0.85
11(T)	597	577	0.97	10	587	0.98	0.5	0.35	0.70	347	3.86	4.50	0.86	0.75	2.89	0.76	2.20	0.862	0.51	1.12	0.60	0.30	0.67
12(P)	401	399	1.00	11	410	1.02	2.5	2.40	0.96	635	7.06	17.00	0.42	0.59	4.18	0.76	3.18	0.875	0.53	1.69	0.57	0.30	0.96
14(P)	304	301	0.99	11	312	1.03	1.5	1.50	1.00	382	4.24	8.80	0.48	0.65	2.75	0.82	2.25	0.875	0.53	1.19	0.57	0.30	0.68
15(P)	429	442	1.03	11	453	1.06	5.0	5.24	1.05	1037	11.52	11.60	0.99	0.81	9.33	0.76	7.09	0.875	0.53	3.76	0.57	0.30	2.14
16(P)	1011	1020	1.01	10	1030	1.02	0.5	0.99	1.98	1025	11.39	8.50	1.34	0.71	8.08	0.82	6.63	0.905	0.64	4.25	0.52	0.33	2.21
34(P)	419	422	1.01	6	428	1.02	4.0	6.75	1.69	1112	12.36	9.60	1.29	0.79	9.77	0.82	8.00	0.914	0.68	5.44	0.50	0.34	2.72
36(T)	610	419	0.69	8	427	0.70	0.5	1.01	2.02	429	4.77	4.20	1.14	0.77	3.67	0.82	3.01	0.770	0.51	1.53	0.84	0.43	1.29
36(X)	242	215	0.89	10	225	0.93	0.5	1.01	2.02	226	2.51	4.20	0.60	0.77	1.93	0.82	1.39	0.770	0.51	0.81	0.84	0.43	0.68

TEST 38 AND TEST 41 NOT REPORTED: QUICK LOOK TEST REPORT NOT AVAILABLE AT TIME OF STUDY

( ) = LOCATION FOR THICKNESS, YIELD AND B2 SELECTION

(T) = TEE

(P) = PIPE

(X) = SPECIAL STUDY: TEE THICKNESS AND YIELD, B2 = 1.0