“配管技術”：1999 年，5 月号，原稿

Mr. E. C. Rodabaugh と配管解析のバックグラウンド

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1. はじめに

筆者は, 配管設計および配管解析という分野で十年ほどの経験がありますが, 現在は米国Ohio州, Columbus にあるScientific Forming Technologies Corporation (SFTC)という会社で熱処理プロセスに対するシミュレーション・ソフトウエアの開発を担当しています．その当時，配管解析の分野で文献をたどっていくと，Mr. E. C. Rodabaugh という研究者が重要な論文を多数発表していることが分かってきました．特に彼の応力係数・たわみ係数に関する研究成果が，すぐに ASME コードに反映されていくことが文献から追跡でき，日本とは違うシステムでしたので非常に興味を持ったことを憶えています.

E.C. Rodabaugh 氏近影

Mr. Rodabaugh が現在筆者が住むColumbusのBattelle研究所に長く勤務されていたことは文献から分かっていましたので, 多分 Columbus かその郊外に住まわれていることは想像できました．そこで，電話帳で住所を調べ，従来から知りたいと思っていた，特に文献には明記されていない配管解析に関する歴史的な背景のようなものをまとめてご質問したところ，ご回答を得ることができました．以下の質疑応答はそれをまとめたものです．なお，Mr. Rodabaugh からは 48 編の論文のリスト(1997 年現在)および近影をいただくことができました．この記事が配管解析とその歴史を知る上でなにかのご参考になれば幸いです.

2. Mr. E. C. Rodabaugh の経歴

Arimoto: まず，簡単にご経歴をお話しいただけますでしょうか.

Rodabaugh: 1939 年に Iowa State College, Ames, Iowa を出て Joseph E. Seagram Co. という会社に 2 年間いました．その後，E. I. Du Pont に 2 年間勤務しましたが，この 4 年間は動力プラントのオペレーションが仕事でした.

1943 年から 1946 年は米国マリタイムサービス（the U. S. Maritime Service）ということで，外洋蒸気船（steam-powered ocean going ships）の機関士（engineer）でした．蒸気タービン船および蒸気レシプロ船（turbine and reciprocating engine ship）の 1 等機関士（chief Engineer）として勤務しました.

1946 年に Kentucky 州の Louisville にあった Tube Turns という会社に入り， 15 年間，配管部品および圧力容器のコンポーネントに関する研究・開発業務に従事しました．ここでは配管系の設計に関するコンサルタント業務および技術文書の作成という仕事にも携わりました．1959 年には The University of Louisville から修士号を受けています.

その後，1961 年に Ohio 州 Columbus にある The Battelle-Columbus Laboratories に移りましたが，配管・圧力容器の設計という分野での仕事を続けることができました．ここでは複雑な問題に対する理論解を求めるというような仕事や，配管部品を解析するためのプログラムの開発なども行いました.

1981 年, Battelle を定年退職した後は，コンサルティング会社 E. C. Rodabaugh Associates, Inc でそれ

まで通り仕事を続けました．1991 年にこの会社を整理した後も，コンサルタントとしての仕事は継続しています.

A:米国マリタイムサービスとはどういうものなのでしょうか．日本ではなじみがありませんが.

B:1936 年の商船法(Merchant Marine Act)によって，“戦時あるいは非常時には海軍の補助軍となる機関”として制定されたものです．米国沿岸警備隊(U．S．Coast Guard）および米国海軍の管轄下にあり，第二次世界大戦中は多くの若者が参加しました．唯一，人種的差別のない機関でした.

A: 米国マリタイムサービスの後，どういう経緯で Tube Turns に入社されたのでしょうか.

R: 戦時中, Kentucky 州の Louisville は私のホームシティでした. 退役して Louisville に帰り, Tube Turns で Mr. Markl の面接を受けたのですが，結果として結構いい条件で採用されました.

A: Tube Turns, Inc.はどのような会社でしたか.

R: Tube Turns は金属製配管部品の製造会社で, 高品質エルボの製作に関する特許を持っていました．1945 年当時，競合製品は少なく Tube Turns は結構な利益を上げていました．会社はティ，レジューサ，金属製ベローズ伸縮継手など，他の配管部品の製造にも徐々に範囲を広げていました．この会社は 1985 ごろ閉鎖されました.

A: Tube Turns は日本の鉄鋼メーカーの住友金属工業に買収されたと聞いたことがありますが，いかがでしょうか.

R: 1961 年に Tube Turns を退社していますので詳しいことは分かりませんが, 住友金属は 1970 年ごろ Tube Turns を買収したと思います．結局，Tube Turns は満足に利益が出せないということで閉鎖されました.

3. Mr. Markl と ANSI Code

A: 初期の配管解析に関する研究については，ASME から出版された二冊の書籍：

(1) Pressure Vessel and Piping Design Collected Papers 1927-1959, 1960, ASME

(2) Pressure Vessel and Piping: Design and Analysis A Decade of Progress, 1972, ASME

に重要な論文が集められています．そこで，これらの論文に関連して前々から知りたいと思っていたことをお聞きしたいと思います．まず，この時期，M. W. Kellogg Company はどうして配管設計に関係する研究に積極的だったかということなのですが.

R: Kellogg は大手の配管設計・施工会社で，研究が商売上でも役に立つと考えたからでしょう.

A: Mr. Markl は彼の論文を見る限りでは ANSI Code を制定する上でかなり貢献したのではないかと思います．Kellogg で彼が応力係数およびたわみ係数を用いた配管解析の簡易法を作り出したのではないでしょうか.

R: Markl が Kellogg にいた時点で, すでに Markl 以外の人間による何種類かの簡易解析法があったようです.

A:異なる種類の配管部品ごとに応力係数を決定するためには実物配管部品に対して膨大な疲労試験が必要になりますが，Kellogg でこのような試験を行うことは可能だったのでしょうか．実際には Tube Turns がやったということですね.

R: Kellogg では Code の規定の元になる疲労試験は実施できませんでした．これらの疲労試験を行ったのは Tube Turns です．結果は以下の論文に掲載されています.

“Fatigue Tests of Welding Elbows and Comparable Double-Mitre Bends”, A. R. C. Markl, Trans. ASME,

Vol. 69, 1947, pp.869-879

"Fatigue Tests on Flanged Assemblies", A. R. C. Markl and H. H. George, Trans. ASME, Vol. 72, 1950, pp.77-87

"Fatigue Tests of Piping Components", A. R. C. Markl, Trans. ASME, Vol. 74, 1952, pp.123-133

当時の Code 制定過程で行われた討論と広範囲に渡る参考文献一覧（1955 年当時の）は以下の文献に含まれています.

"Piping-Flexibility Analysis", A. R. C. Markl, Trans. ASME, February, 1955.

A: Mr. Markl は Kellogg から Tube Turns, Inc.へ移りましたが，どのようなことからでしょうか.

R: Tube Turns は今後自分たちの製品を拡販していくためには地道な研究活動（substantial research work）が必要と考え，準備を始めていました．Markl は Kellogg よりもよい条件を提示されたのでしょう.

A: Mr. Markl はどのような方だったのでしょうか.

R: Markl は非常に有能な技術者（a highly competent engineer）で優れたテクニカルライターでした．彼は質の高い仕事をし，同僚にも同じことを望みました.

A: その他，Mr. Markl についてなにかお話し願えないでしょうか.

R: Markl は退社する前の数年間，金属製ベローズ伸縮継手の開発と試験に携わっていました．彼の最後の論文は以下のものです.

"On the Design of Bellows Elements", A. R. C. Markl, Presented at the National Distinct Heating Association's 55th Annual Meeting, June 1964, Niagara Falls, Ontario, Canada

A: あなたが Tube Turns で行った内圧がエルボのたわみ係数と応力係数におよぼす効果についての研究ですが，研究の目的はどういうことだったのでしょうか．このような効果はエルボの肉圧と径の比が非常に小さい場合に顕著になるはずですが，当時このようなエルボの需要があったのでしょうか.

R: 1955 年当時，Tube Turns の製品として，肉圧と径の比が 0.01 程度のエルボが結構ありました.

A: フランジ継ぎ手の圧力ー温度レイテェイング制定のためにどのような実験が行われたのでしょうか．日本で調べた際には，適切な文献が見つからなかったように記憶しています.

R: ANSI B16.5 フランジ継ぎ手の圧力ー温度レイティングに関しては，この記事の最後に掲載されている論文リストにある論文(10),(18),(28),(33) および(34) をご覧ください.

4. Battelle 研究所および ASME Code

A: 1961 年に Battelle 研究所の方に移られていますが，どのような理由からでしょうか.

R: 1960 年，Tube Turns は特許権が消滅したことにより減益となり，研究業務が削減されることになりました．私は Battelle の技術者と一緒に仕事をしたことがあり，Battelle が私と同じ分野の研究をやっていることを知っていました．彼らは Tube Turns よりもいい条件を提示してきたので Battelle に移ることに決めました.

A: 当時，商用の原子力プラントのために ANSI B31.7, Nuclear-Piping-System Code の制定が準備されていたと思います．コードに規定されている簡易解析のための式は誰が作り上げたものなのでしょうか.

R: B31.7 のクラス 1 配管の式は B31.7 Code 制定のための委員会で決められたものです．配管グループの委員長で最もこれに寄与したのは D. F. Landers で，現在は Teledyne Brown Engineering におられます.

A: ORNL 配管プログラム（the ORNL piping program）に関連して B31.7 の応力係数（stress indices）をあ

なたは 6 ヶ月ほどでまとめあげた，というように S. E. Moore は記事：

S. E. Moore, “The Contributions of the ORNL Piping Program to Nuclear Piping Design Codes and Standards”, Trans. ASME, Journal of Pressure Vessel Technology, pp224, 1977

に書いています． ORNL 配管プログラムと応力係数制定の背景についてお話し願えないでしょうか.

R: ORNL 配管プログラムは.S. E. Moore の記事にあるように，配管部品の応力係数とたわみ係数を制定するための基礎研究を目的として，B31.7 委員会からの要請により Oak Ridge National Laboratory (ORNL)で 1967 年から開始されました．応力係数制定の背景については，本記事の最後の論文リストにあるレポート類を見ていただくしかありません．たとえば，論文(26)は B 係数に関する 104 ページの詳細な報告書です.

A: ORNL 配管プログラムはいつまで続いたのでしょうか.

R: 1980 年ごろまででした.

5. 展望

A: 若手の配管技術者や研究者にどのようなことを期待されるでしょうか.

R: 現時点で手にできる種々のデータはその裏に非常に深い背景や経緯がある，ということをよく認識してほしいと思います.

弾・塑性解析は，配管部品や配管系の評価・設計でもっと利用すべきでしょう．それによる結果の評価が問題になるかもしれません．そのためには注意深く計画された実験が必要になるでしょう.

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(3) Comparisons of ASME Code Fatigue Evaluation Methods for Nuclear Class 1 Piping with Class 2 or 3 Piping, NUREG/CR-3243, June 1983

(4) Preparation of Design Specifications and Design Reports for Pumps, Valves, Piping and Piping Supports Used in Safety-Related Portions of Nuclear Power Plants, NUREG/CR-4943, June 1987

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(8) Evaluation of the Plastic Characteristics of Piping Products in Relation to ASME Code Criteria, NUREG/CR-0261, July 1978

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January 1976

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(14) Design and Strength of Welded Pipe Line Branch Connections, with H. H. George, Proc. ASCE, J. of Pipeline Div., PL-1, March 1957

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(16) Stresses in Tapered Transition Joints in Pipelines and Pressure Vessels, with Atterbury, Trans. ASME, J. of Engr. for Industry (1962)

(17) Evaluation of the Bolting and Flanges of ANSI B16.5 Flanged Joints, ASME Part A Design Rules, with S. E. Moore, ORNL/Sub/2913-3, September 1976

(18) Performance of 6061-T6 Aluminum Flanged Pipe Assemblies Under Hydrostatic Pressure, with George, Holt, ASME Paper 56-PET-19

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質疑応答(英文)

2. Mr. Rodabaugh's Background

Arimoto: Would you tell us your background briefly?

Rodabaugh: I worked for Joseph E. Seagram Co. for two years and for E. I. Du Pont for two years, after I received my B. S. degree from Iowa State College, Ames, Iowa in 1939. For those four years I was engaged in power plant operations. From 1943 to 1946 I was with the U. S. Maritime Service, working as Engineer on steam-powered ocean going ships. I obtained a Chief Engineer's license and served as Chief Engineer on both turbine and reciprocating engine ship. In 1946, I joined Tube Turns in Louisville, Kentucky. I remained with them for over 15 years, engaging in research and development work on programs relative to piping and pressure vessel components. I also served as a piping system design consultant and participated in the preparation of technical publications on piping system designs. In 1959, I received my M. S. from the University of Louisville.

I joined the Battelle-Columbus Laboratories, Columbus, Ohio in 1961. I remained with them for 20 years, during which time I continued to work in the field of design of piping and pressure vessels. I has developed theoretical solutions to a number of complex problems involved in the design of piping and pressure vessel components and has written a number of computer programs applicable such components. In 1981, I retired from Battelle and started my own consulting firm, E. C. Rodabaugh Associates, Inc. I continued my work on piping and pressure vessels. In 1991, the firm was dissolved and since then, I have continued my work as a consultant.

Arimoto: What is the U. S. Maritime Services?

Rodabaugh: Merchant Marine Act of 1936, enacted by Congress, created the U.S. Merchant Marine and the U.S. Maritime Service to "serve as a naval or military auxiliary in time of war or national emergency." U.S. Maritime Service operated four basic training bases for teaching seamanship and weapons training; officer candidate schools; specialized training, and ten vessels to train over 200,000 men recruited throughout the country. USMS administered by U.S. Coast Guard and U.S. Navy. During World War II many young men were sent to U.S. Maritime Service by Navy and Coast Guard recruiters. The USMS was the only Service that did not discriminate racially.

Arimoto: Why did you work for Tube Turns after the U.S. Maritime Service?

Rodabaugh: During the war, Louisville, KY, was my "home" city. After the war, I return to Louisville and, as a result of a job interview with Mr. Markl, I was offered a job at what was then a good salary.

Arimoto: What company was Tube Turns, Inc.?

Rodabaugh: Tube Turns, Louisville, KY, was a manufacturer of metal piping components. Tube Turns had a patented method of manufacturing high-quality elbows. In 1945, the competition was small and Tube Turns could make large profits. They gradually expanded into other piping products such as tees, reducers and metal-bellows expansion joints. Tube Turns was closed in about 1985.

Arimoto: I have heard that Tube Turns was taken over by Sumitomo Metal, a Japanese steel maker. Do you know the story?

Rodabaugh: I left Tube Turns and Louisville in 1961. I think Sumitomo Metal bought Tube Turns around 1970.

Apparently, Tube Turns was not sufficiently profitable, hence Sumitomo closed Tube Turns.

3. Mr. Markl and ANSI Code

Arimoto: We can learn easily early research works of piping analysis through papers in the following two books published by ASME.

Pressure Vessel and Piping Design Collected Papers 1927-1959, 1960, ASME

Pressure Vessel and Piping: Design and Analysis A Decade of Progress, 1972, ASME

I have some questions that I wanted to know answers in Japan from some papers in the above books. First, why was Kellogg Company so active to do researches on the piping design at that time?

Rodabaugh: Kellogg was a major designer and fabricator of piping system. Their commercial interests were served by their research work.

Arimoto: I think Mr. Markl contributed a lot for specifying the ANSI Code according to his papers. I guess he created the concept of the simplified method of piping analysis by using stress intensity and flexibility factors at Kellogg. Is it true?

Rodabaugh: When Markl was at Kellogg, there were several methods of simplified piping system analysis by other-than Markl.

Arimoto: Was it possible for Kellogg to carry out a lot of fatigue experiments for specifying stress intensity factors of each piping component? Actuary did the Tube Turns does?

Rodabaugh: Kellogg did not carry out the fatigue tests which form the basis for Code rules. These fatigue tests were carried out at Tube Turns. Results were published in the Papers:

"Fatigue Tests of Welding Elbows and Comparable Double-Mitre Bends", A. R. C. Markl, Trans. ASME, Vol. 69, 1947, pp.869-879

"Fatigue Tests on Flanged Assemblies", A. R. C. Markl and H. H. George, Trans. ASME, Vol. 72, 1950, pp.77-87

"Fatigue Tests of Piping Components", A. R. C. Markl, Trans. ASME, Vol. 74, 1952, pp.123-133

Discussion of Code rules and an extensive Bibliography (as of 1955) are contained in the paper:

"Piping-Flexibility Analysis", A. R. C. Markl, Trans. ASME, February, 1955.

Arimoto: Why did Mr. Markl move to Tube Turns, Inc.?

Rodabaugh: Tube Turns was prepared to undertake substantial research work to further the selling of their products. Markl was presumably offered a better salary than he was getting at Kellogg.

Arimoto: What was Mr. Markl like?

Rodabaugh: Markl was a highly competent engineer and an excellent technical writer. He did high-quality work and insisted on high-quality from those who worked for him.

Arimoto: If possible, would you give us episodes about him?

Rodabaugh: In the last few years of Markl's career, he worked at Tube Turns to develop and test metal bellows expansion joints. His last published paper is: "On the Design of Bellows Elements", A. R. C. Markl, Presented at the National Distinct Heating Association's 55th Annual Meeting, June 1964, Niagara Falls,

Ontario, Canada.

Arimoto: I know you did the research on the effect of internal pressure on flexibility and stress-intensification factors of elbows at Tube Turns. What was the purpose of the research? I think the effect is significant when the ratio of thickness to diameter become small. Did industry need such elbows at that time?

Rodabaugh: In about 1955, Tube Turns was routinely making and selling elbows with ratio of thickness to diameter of around 0.01.

Arimoto: What kind of experiment was carried out for specifying the pressure-temperature ratings of flanged joint? I remember reports on the rating would be just for Tube Turns, so that I could not get them in Japan.

Rodabaugh: For pressure-temperature ratings of ANSI B16.5 flanged joints, see Reference (10),(18),(28),(33) and (34) of " Papers Authored or Co-Authored by E. C. Rodabaugh".

4. At Battelle laboratory and ASME Code

Arimoto: Why did you move the Battelle Laboratories in 1961?

Rodabaugh: By 1960, Tube Turns patent had expired; they were making less profit and beginning to cut back on research work. I had worked with an engineer at Battelle, thus I was aware that Battelle was doing research in my field. They offered a salary that was better than at Tube Turns thus, when invited to move to Battelle, I did so.

Arimoto: At that time, ANSI B31.7, a nuclear-piping-system code had been preparing for a commercial nuclear plant. Do you know who created equations for the simplified analysis of the Code?

Rodabaugh: The equations in B31.7 for Class 1 piping were a result of B31.7 Code Committee work. The chairman of the piping group, and principal contributor, was D. F. Landers, now with Teledyne Brown Engineering.

Arimoto: You specified the stress indices of the B31.7 relating the ORNL piping program in less than 6 months according to the following article by S. E. Moore.

S. E. Moore, "The Contributions of the ORNL Piping Program to Nuclear Piping Design Codes and Standards", Trans. ASME, Journal of Pressure Vessel Technology, pp224, 1977

Would you tell us in detail about the ORNL piping program and a background of specifying the stress indices?

Rodabaugh: The ORNL Piping Program was started since 1967 to develop and qualify stress indices and flexibility factors for several years under the B31.7 Committee at Oak Ridge National Laboratory (ORNL) as shown in the article by S. E. Moore. Details of the work are described in several of reports listed in "Papers authored or co-authored by E. C. Rodabaugh". For example, Reference (26) is a 104 page report giving details of the background of B-indices.

Arimoto: How long did the ORNL program last?

Rodabaugh: To about 1980.

5. Outlook

Arimoto: What do you expect young piping engineers and researchers?

Rodabough: Hopefully, young engineers will be aware of the tremendous background of data that exists at present.

Elastic-plastic analysis methods are expected to be developed, validated and widely used in the not too distant future. These analyses should provide a better basis for the evaluation and design of piping components and piping systems.

The “validation” part of using elastic-plastic analyses may be the major impediment to confident use of such analyses. Probably additional, carefully planed and conducted testing will be needed for adequate validation.