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ASEISMIC CONSIDERATIONS OF THE SEISMIC CATEGORY III PIPING IN KNPP

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ABSTRACT

The seismic effects for the SC-III (Seismic Category III) process piping are normally not considered in KNPP (Korean Nuclear Power Plant) since the SC-III piping is categorized as non-seismically qualified piping in piping system design specifications. Article 101.5.3 of ASME B31.1, however, requires that earthquake effects be considered in the design process of piping systems using the site-specific seismic effect as a guide to assess the seismic loads. Nevertheless, it does not specify the methodology for analysing the piping systems. The purpose of this study is to provide piping stress engineers with the procedures for designing SC-III piping in accordance with the requirements of the KBC (Korean Building Code) similar to IBC (International Building Code) and other industry codes & standards as applicable to the designed functions of the piping systems. The results of the study are used to create seismic spans and support loads for SC-III piping systems. One of the results of the study is the importance factor (I_P) of 1.5 for major equipment such as turbine-generator, heat exchangers, pumps, and condensers, and piping containing hazardous (toxic or explosive or flammable) materials, which are designed by the equivalent static force and relative displacement instead of seismic loads of SSE and/or OBE, based on the methodologies given in KBC. Also, the pipe spans and support loads developed in this study may be used for the seismic design of the new piping or seismic retrofit of the existing piping that was not supported seismically but are to be checked for seismic capacity and upgraded as necessary using simplified design rule.

INTRODUCTION

SSCs(Structures, Systems, and Components) in KNPP(Korean Nuclear Power Plant) are seismically designed in accordance with the seismic classification criteria in USNRC Regulatory Guide 1.29 in fulfilling the requirement of GDC (General Design Criteria) 2 per Appendix A in 10 CFR 50. All the SSCs are seismically categorized into SC (Seismic Category)-I, SC-II, and SC-III per the requirements of the DCM (Design Criteria Manual) of the project. The SSCs for SC-I are those that are to be designed to remain functional in the event of an SSE (Safe Shutdown Earthquake). The SSCs for SC-II are designed to preclude a gross structural failure that results from a seismic event and that degrades adjacent safe shutdown equipment/component, or non-nuclear safety SC-I component, to an unacceptable level. All SSCs not covered by SC-I and SC-II shall be classified as SC-III and be designed without reflecting the seismic responses of building structures in the event of an SSE, but with reflecting the effects of earthquake motions in accordance with the KBC (Korean Building Code) similar to IBC (International Building Code) and other industry codes & standards as applicable for their design functions. The seismic effects for the SC-III process piping in KNPP are normally not considered since the SC-III piping is categorized as non-seismically qualified piping in piping system design specifications. Non-nuclear piping systems routed in Turbine building such as MS (Main Steam), FW (Feed Water), ES (Extracted Steam), TA (Turbine Auxiliary), etc. are classified as SC-III and consequently non-seismically designed per the piping system design specifications. For the well-experienced piping stress engineers, however, these piping systems are considered as essential to remain functional in the event of an earthquake and tactfully designed by aseismatic concept since a failure of this piping from the seismic event can cause any loss of power. ASME B31.1 Article 101.5.3, furthermore, requires that earthquake effects be considered in the design of piping systems and their supports, using data for the site as a guide in assessing the forces involved. From those engineering aspects, it is strongly recommended for piping stress engineers to adopt an aseismatic concept into SC-III piping design. Unfortunately, however, in-depth studies on the seismic effects for the SC-III piping systems in engineering fields have rarely been performed in KNPP.

This paper attempts to provide piping engineers with the aseismatic methodology through the span evaluations based on simplified design rule, such as the constant-pitch span rule or the seismic load coefficient method specified in ASME Sec. III Appendix N-1225, for designing the SC-III piping by utilizing the earthquake requirements of the KBC and ASME B31.1 as applicable to the designed functions of the piping systems. Also, pipe spans and support loads for SC-III piping adopting earthquake effects of Ulchin site where SHN 1&2 KNPP is located are developed and presented as a sample case for the seismic design of the new piping or seismic retrofit of the existing piping that was not supported seismically but is to be checked for seismic capacity and upgraded as necessary using simplified design rule.

I. DESIGN PARAMETRS FOR EARTHQUAKE IN KNPP

Earthquake Area and Area Coefficient

Earthquake areas in the Republic of Korea are grouped into EA-1 and EA-2 [1]. The northern region of Gangwon province including Hongcheon, Cheolwon, Chuncheon, etc., the southwest region of Jeollanam province including Mooan, Younggwang, Jindo, etc., and Jeju province, being shaded areas with pink as shown in Figure 1, are grouped into EA-2. All the regions except EA-2 are grouped into EA-1. Area coefficient, A_C, reflecting local seismic effects per earthquake area is 0.11 for EA-1, while 0.07 for EA-2 [1]. Ulchin site, circled area in Fig. 1, where SHN 1&2 KNPPs are located, as a sample case in this paper, belongs to EA-1 and A_C refers to 0.07.

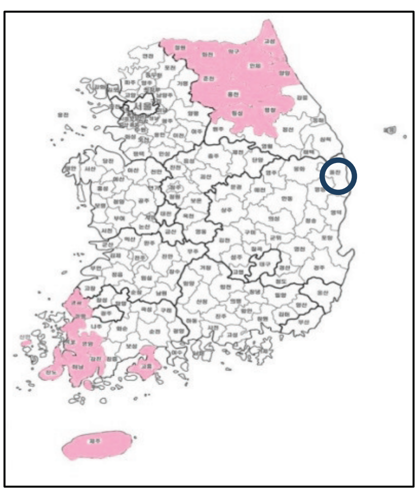

Figure 1. Earthquake Areas in the Republic of Korea

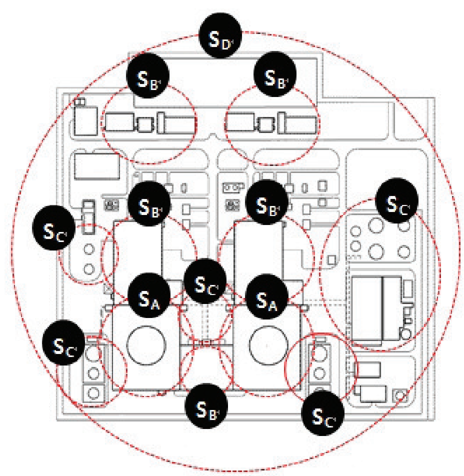

Figure 2. Site Classes in Ulchin Site

Site Class

Site classes are classified into 5 groups from S_A to S_E based on site soil properties or shear wave velocities reflecting average characteristics of upper part of the ground by 30 meters as tabulated in Table 1 [1]. If a ground is filled with hard-conditioned earth and sand, the site is classified as S_D per Table 1. For Ulchin

NPP site, Nuclear Island with Containment building and Auxiliary building is defined as site class S_A whereas Turbine building, Compound building and Circulating Water Intake structures are defined as S_B as shown in Figure 2. All the site classes for NPP are schematically illustrated in Figure 2 as a reference.

Table 1. Site Classes per Ground Conditions

Site Class	Ground Condition	Shear Wave Velocity(m/s)
S_A	Hard Rock	Over 1,500
S_B	Rock	760~1,500
S_C	Very Dense Soil/Soft Rock	360~760
S_D	Stiff Soil	180~360
S_E	Soft Clay Soil	Under 180

Table 2. Design Spectral Accelerations

Site Class	Short Period(S_{DS})		1-Second Period(S_{D1})	
	EA-1	EA-2	EA-1	EA-2
S_A	2.0 MA_C	1.8 MA_C	0.8 MA_C	0.7 MA_C
S_B	2.5 MA_C	2.5 MA_C	1.0 MA_C	1.0 MA_C
S_C	3.0 MA_C	3.0 MA_C	1.6 MA_C	1.6 MA_C
S_D	3.6 MA_C	4.0 MA_C	2.3 MA_C	2.3 MA_C
S_E	5.0 MA_C	6.0 MA_C	3.4 MA_C	3.4 MA_C

Design Spectral Accelerations for Short Period (S_{DS}) and 1-Second Period (S_{D1})

Design spectral accelerations for an earthquake area are defined as a function of a statistical amplification factor of magnitude of an earthquake for the reoccurring period of 2,500 years, M, and area coefficient, A_C, subjected to the site. As shown in Table 2, design spectral accelerations are expressed as forms of equations for short period (S_{DS}) and 1-second period (S_{D1}) [1]. As a result of searches on the records of earthquake in Korea, M is defined as 1.33 since the magnitude of earthquake on the reoccurring period of 2,500 years is defined from the two-third of the twice of the magnitude of earthquake on the reoccurring period of current 500 years. For Ulchin NPP site, each S_{DS} for EA-1 per Table 2 is calculated to be 0.3658g from $2.5MA_C(=2.5 \cdot 1.33 \cdot 0.11)$ for site class S_B, 0.4389g for S_C as same calculation manner for S_B, and 0.5267g for S_D, whereas each S_{D1} for EA-1 is calculated to be 0.1463g for site class S_B, 0.2341g for S_C, and 0.3434g for S_D.

Seismic Design Category (SDC)

SDCs are classified into 4 groups from A to D per the range of design spectral accelerations. SDC for SSCs in KNPP is defined as 'D' per KBC if S_{DS} is greater than or equal to 0.33g, 'C' if S_{D1} is between 0.16g and 0.33g, and 'A' if S_{D1} is lower than or equal to 0.16g. Whereas, SDC is defined as 'D' if S_{D1} is greater than or equal to 0.14g, 'C' if a S_{D1} is between 0.06g and 0.14g, and 'A' if S_{D1} is lower than or equal to 0.06g. For Ulchin NPP site, SDCs for all the SSCs are determined to be 'D' since values of S_{DS} are greater than 0.33g and also all the values of S_{D1} are greater than 0.14g as calculated before for all site classes. If SDC is defined as 'D', either the equivalent static analysis or the detailed dynamic analysis can be applied to piping design per the building code.

Importance Factor (I_P) for Piping and Pipe Supports

Importance factor *(I_p)* for piping and pipe supports is 1.0 except the following for which I_p is 1.5: (i) Piping and pipe supports for the systems related to the human life and safety, and required to be functional after earthquake such as fire protection system, (ii) Piping and pipe supports for the systems containing hazardous (toxic, explosive or radioactive waste) or flammable materials such as fuel gas, ammonia, lube oil, chemical feed and hydrogen gas. Note that radioactive waste system piping and pipe supports are required to be designed for earthquake load per RG 1.143 and are not within the scope of this review, (iii) Piping and pipe supports for the systems needed for continued operation of the power plant or their failure could impair the continued operation of the power plant, which is interpreted to include piping and pipe supports supporting major equipment needed for the continued operation of the power plant, such as turbine-generator, heat exchangers, pumps etc., which are expected to be operable during and after "Inspection Level Earthquake" above which plant has to be shut down for inspection.

From the above, importance factor for the most of the Seismic Category III piping and pipe supports for SHN 1&2 can be safely considered to be 1.5 for conservative and practical purposes unless it can be proved otherwise, i.e., they are not needed for continued operation of the power plant or their failure could not impair the continued operation of the power plant.

II. DEVELOPMENT OF SC-III PIPING SPANS

Since piping and pipe supports in general are the mechanical components permanently attached to the building structures, and SDC for SSCs in Ulchin NPP site is defined as 'D', SC-III piping and pipe support shall be designed to withstand equivalent static load and displacement due to a local earthquake determined per the building code.

Equivalent Static Force

Per the building code, equivalent static load F_p due to earthquake is determined by the Equation (1) [1]. F_p shall be considered to be acting on the centroid of piping mass and shall be independently applied in both axial and lateral directions.

$$F_p = \frac{0.4\alpha_p S_{DS} W_p}{\left(R_p / I_p\right)}\left(1 + 2\frac{z}{h}\right). \tag{1}$$

In Equation (1), α_p is amplification factor between 1.0(rigid type joint) and 2.5(flexible type joint), and let 1.0 for piping system. I_p is importance factor, 1.0 or 1.5, and let 1.5 for piping system. R_p is response correction factor between 1.0 and 5.0, and let 1.25 for piping system with low strain capacity material and support (welded steel pipe with ε of 0.14% within elastic range). S_{DS} is short period design spectrum acceleration per site class. For Ulchin NPP site, let 0.3568g for site class S_B, 0.4389g for site class S_C, and 0.5267g for site class S_D. W_p is operating weight of piping span. Variable z is piping attachment elevation and h is roof elevation. Let 1.0 for the shape factor *z/h* for conservatism. If we put those defined values of variables into Equation (1), we can obtain Equation (2) for the maximum F_p for piping systems in a building or area with each site class for Ulchin NPP site.

$$F_p = kW_p \text{, where } k\text{=0.3792 for site class } S_D\text{, 0.3160 site class } S_C\text{, and 0.2634 for site class } S_D. \tag{2}$$

Since Equation (1) in KBC is not clear in defining vertical force and combining the forces in different directions, Section 13.3.1 of ASCE/SEI is utilized for clarification [2], which requires the force F_p be applied independently at least at two orthogonal horizontal directions in combination with service loads associated with piping, as appropriate. It also requires for vertically cantilevered systems, but the force F_p shall be assumed to act in any horizontal direction. Since KBC requires F_p be applied independently in axial and lateral directions but is not clear about combination method of the spatial components, for the purpose of generating seismic piping spans, F_p in the two orthogonal directions lateral to the pipe span is conservatively combined by SRSS(Square Root of the Square Sum). Also note that per Section 0306.2.2 of KBC, seismic load coefficient (S_f) of 0.7 is to be used for the load combination when the design is based on allowable stress concept, as in the case of piping stress analysis per ASME B31.1.

Seismic Span

Maximum seismic span for the SC-III piping that can withstand equivalent seismic force F_p calculated above is calculated using the following equation in accordance with the paragraph 104.8.2 of B31.1 Code. Per the code, the effects of pressure, weight, other sustained loads, and occasional loads including earthquake shall meet the requirement of Equation (3).

$$\frac{PD_O}{4t} + \sigma_W + \frac{0.75iM_B}{Z} \le 1.2S_h. \tag{3}$$

In Equation (3), P is design pressure in psi, and maximum design pressure is assumed to be 300 psi in this study. This assumption is very reasonable since the portion of pressures exceeding 300 psi is actually 20% or less in KNPP. For the pipe size, D_o is outside diameter (inch) of a pipe, and t is pipe thickness (inch). Stress intensification factor i per a joint type is 1.9 for large-bore pipes (greater than 2″ in diameter) and 2.1 for small-bore pipes (2″ or under in diameter) conservatively. Here, $0.75i$ is 1.425 for large-bore pipes and 1.575 for small-bore pipes. σ_w is stress(psi) due to dead weight load, and maximum weight stresses of 2,300 psi based on the suggested maximum hanger span in B31.1 Code, are assumed in this study. M_B is bending moment (in-lb) due to equivalent static force (F_p) acting in the mid span. In this study, average of the maximum bending moments that can occur in the simply supported ($M_B = F_pL_S/4$, ft-lbs) and fixed-fixed ($M_B = F_pL_S/8$, ft-lbs) beam model is used, where L_S is seismic span length (feet). The force is applied to each of the horizontal directions (north-south & east-west) and vertical direction independently, i.e., moments due to independent forces both at horizontal and vertical directions are combined by SRSS. w_p is total unit weight(lb/ft) of the pipe including content and insulation, and W_p is total pipe weight of the span(=w_pL_S, lbs). Z is sectional modulus (in^3) of a pipe. S_h is allowable stress (psi) of a pipe material, and 15,000 psi is conservatively assumed in this study. Rewriting the Equation (3) for L_S by putting above defined values of variables, seismic load coefficient (S_f) of 0.7, and Equation (2) in term of unit weight w_p into Equation (3) becomes as below Equation (4).

$$L_S \leq \sqrt{\frac{(18{,}000 - 300D_O/4t - 2{,}300)Z}{9\sqrt{2}(0.75i)(0.7)kw_P/4}}\,. \tag{4}$$

Seismic Support Load

Support reactions for both simply supported and fixed end model are:

$$R = S_f F_p = 0.7kw_pL_S \text{ for allowable stress design.} \tag{5}$$

From the Equation (4), SC-III piping spans for site class S_D on the various pipe sizes filled with gas/steam and water are simply calculated, and the results are illustrated in Figure 3 for insulated piping with Ca-Si (Calcium-Silicate) in 1.5″ thickness. Also, Table 3 shows the seismic support loads calculated from the Equation (5) on the same conditions of deriving seismic spans.

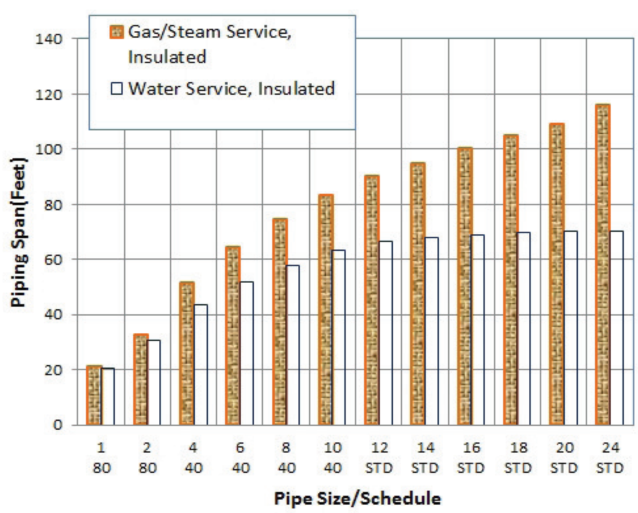

Figure 3. Seismic Span L_S for SC-III Piping

Table 3. Seismic Support Loads (lbs)

NPS/Sch.	Gas/Steam	Water
1/80	25	25
2/80	70	75
4/40	200	240
6/40	410	500
8/40	690	870
10/40	1,070	1,400
12/STD	1,400	1,900
14/STD	1,600	2,230
16/STD	1,930	2,800
18/STD	2,280	3,410
20/STD	2,630	4,070
24/STD	3,360	5,500

III. ENGINEERING REVIEW OF SEISMIC PIPING SPANS

A piping system generally consists of multiple spans with horizontal and/or vertical support spacing. No matter how complicate a piping is routed, the configuration of each segment consisting of the piping can be easily simplified using horizontally or vertically straight spans, bent spans or branched spans with or without lumped masses such as valves or flanges. Some piping span models used in this study are presented in Figure 4 through Figure 6. Piping spans in the models are qualified for the dead weight and the combined load of dead weight & seismic load. For support design in these models, seismic supports are considered on the lateral sides of spans as shown in Figure 4 through Figure 6 after deciding the proper locations of dead weight supports on the gravitational sides of spans based on the locations of anchor plates or structural steel beams. For the convenience of an engineering aspect, span lengths in all models are developed on the basis of straight span length L_O in the span model-H, where L_O is defined as the horizontal or vertical support spacing on the horizontally or vertically straight piping segments as shown in Figure 4. The span L_1 adjacent to L_O in Figure 4 shall be also tactfully reviewed in an engineering aspect to prevent the excessive upward deflection from experiencing uneven mass distribution in the piping system, and will be the lower bound of the allowable span range of L_O. The span model-L in Figure 5 illustrates the maximum lateral support spacing L_L as N times as long as L_O, where N is introduced to develop the LVSSR (Lateral to Vertical Support Span Ratio). If lumped masses like valves are mounted on the mid-span of piping segments, the support span shall be shortened in some extent to meet the deflection or stress requirement. The model-W in Figure 6 considers the effect of lumped mass W by multiplying the span reduction factor β.

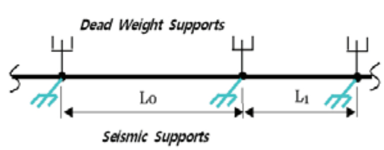

Figure 4. Span model-H

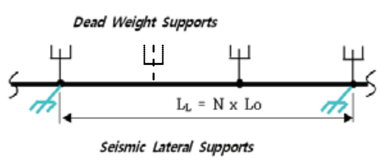

Figure 5. Span model- L

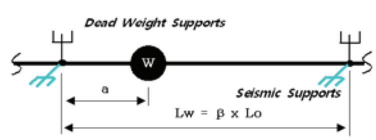

Figure 6. Span model –W

Allowable Seismic Span Length L_O

For site engineers charged for the scope of piping design, the most important thing to develop useful seismic spans is how to determine the allowable range for the straight span L_O as illustrated span model-H in Figure 4 because it directly depends on the number of pipe supports in view of cost effect. Piping span, normally, is referred to from the suggested pipe support spacing table in ASME B31.1, Table 121.5. However, seismic piping spans should be qualified for seismic loads per site specific conditions since the suggested hanger spacings in the Table are normally referred to for DW (Dead Weight) analysis. As shown in Figure 7, the suggested spans in the Table is applicable to the SC-III piping span L_O for the span model-H since all the spans per the Table are less than the derived seismic spans L_S per Equation (4). This means that the piping span L_O based on DW analysis is seismically qualified for an earthquake if a span L_O per the Table is chosen to the allowable seismic span for the SC-III piping on an earthquake. For KNPP, the maximum allowable seismic span length is recommended to 1.25 times the spans specified in the Table [3]. If L_S is chosen as L_O, supports should be designed by rigid types instead of rod hangers.

LVSSR (Lateral to Vertical Support Span Ratio)

Allowable lateral support spacing L_L on a straight piping segment as span model-L in Figure 5 is directly defined as seismic piping spans L_S without referring to from DW analysis due to gravitational effect, since seismic span L_S calculated from Equation (4) is derived from the equivalent static load F_p applied in each of the horizontal directions (north-south & east-west) and vertical direction independently. Therefore, LVSSR is defined as the result of L_S divided by L_O. Figure 8 shows that LVSSR has ranges of 2.0~3.5 for piping filled with water or gas/steam. In this study, the allowable number of N is recommended as in the vicinity of 3.0 per upper bound of range, since all of the suggested spans applied to LVSSR are based on the maximum allowable spans from the code or guidelines based on the very conservative manner for multipurpose. Through the peer review of a plenty of stress calculations of seismic piping in KNPP, the factor 3.0 of LVSSR is confirmed as very reasonable.

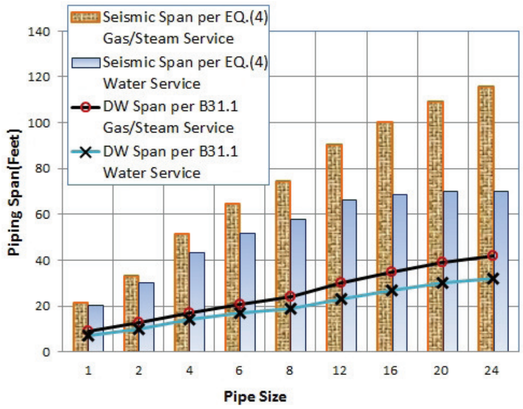

Figure 7. Allowable Span Lengths for SC-III Piping

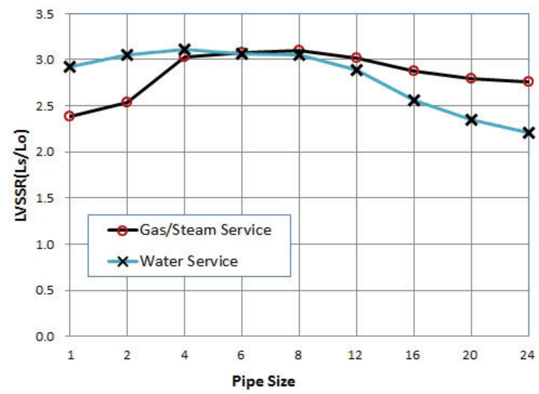

Figure 8. LVSSR for SC-III Piping

Span Reduction Factor β

If a lumped mass W is mounted on the point 'a' of the piping span as shown span model-W in Figure 6, the span L_O shall be shortened using the span reduction factor β which is defined as the ratio of the span L_W with the lumped mass W to the span L_O with a self-weight w of pipe. If we set that each of the maximum stress due to the pipe self-weight w and the lumped mass W is same, we can obtain Equation (5) to solve the span reduction factor β, where $\beta=L_W/L_O$, $\alpha=W/wL_O$, $K=a(L_W-a)/L_W^2$, and Equation (6) is span reduction factor β solved from Equation (5) [3].

$$\beta^2 + 8\cdot\alpha\cdot K\cdot\beta = 1 \ , \tag{5}$$

$$\beta = \frac{-\varphi + \sqrt{\varphi^2 + 4}}{2} \ , \text{ where } \varphi = 8\alpha K \ . \tag{6}$$

The results of β are presented in Figure 9 through the optimal curve fitting. Though this reduction factor is derived from the static stress criteria, it gives very good approximation for site engineers to determine the seismic piping span since the difference of span sensitivity between static and seismic loads is not too significant. For the case that a concentrated weight acts on the middle of span, the difference of 1.4% or less between reduction factors by static and seismic loads has been reported [4].

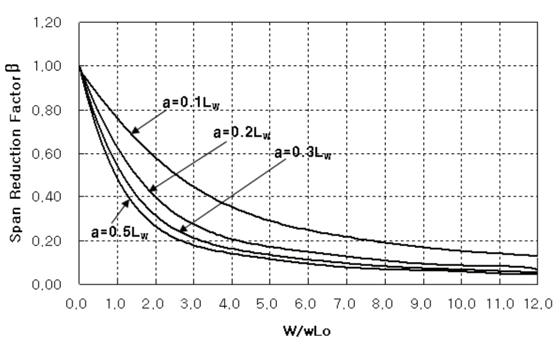

Figure 9. Span Reduction Factor β for SC-III Piping

Relative Building Displacement

Maximum relative building displacement between the two connection points at different elevations X and Y within the same structure due to earthquake shall not exceed the D_P, as defined in Equation (7) per the building code KBC,

$$D_P = (X - Y)\frac{\Delta_{aA}}{h_{sx}} \ , \tag{7}$$

where, D_P is seismic relative building displacement to be absorbed by non-structural components due to earthquake, h_{sx} is floor elevation used for defining allowable displacement between floors, Δ_{aA} is allowable displacement at structure A and defined $0.01h_{sx}$ for NPP piping per the building code KBC, X is height between the ground and upper attachment point, and Y is height between the ground and lower attachment point. For illustrative purpose, maximum relative building displacement D_P for SC-III piping located within Turbine building, whose adjacent horizontal supports are attached to the elevations 160' and 155' shall not exceed 0.6″ per Equation (7). In lieu of the above, OBE(Operating Basis Earthquake) building displacement calculated by Civil/Structural group using SASSI or stick model may also be used if available. Note that relative displacements within the same structure are typically considered insignificant for piping analysis. However, the effect of relative displacement of the piping supported from two independent structures such as auxiliary and turbine buildings shall be evaluated.

CONCLUSIONS

From the study results through several topic studies, the following conclusions are derived:

1) Span evaluation based on simplified design rule per the equivalent static force is very reasonable in considering the aseismic effects due to an earthquake for the SC-III piping.
2) For the equivalent static force, importance factor for the SC-III piping and pipe supports can be safely considered to be 1.5 for conservative and practical purposes.
3) For the seismic piping spans, three times the piping spans specified in the ASME B31.1 Table 121.5 is recommended as the allowable of LVSSR for all pipe sizes.
4) Seismic piping spans, support loads and span reduction factors developed as an illustrative example for Ulchin site in this study are adoptable for the seismic design of a new piping or seismic retrofit of the existing piping that was not supported seismically but is to be checked for seismic capacity and upgraded as necessary in KNPP.

REFERENCES

[1] 2005 Korean Building Code (KBC), Architectural Institute of Korea.
[2] ASCE/SEI Standard 7-05, Minimum Design Loads for Buildings and other Structures.
[3] Joon-Ho Lee, “Seismic Spans for Cold Piping based on Simplified Dynamic Analysis in APR1400,” Proceedings of ICONE17, Paper No. ICONE17-75808, ASME 2009.
[4] Joon-Ho Lee, “A Sensibility Study of the Piping Spans Following the Weight Variations of the In-line Components,” Proceedings of ICAPP2011, Paper No. 11068, ANS, 2011.
[5] ASME B31.1, Power Piping Code, 1998 Edition thru 2000 Addenda.
[6] 2012 International Building Code (IBC), International Code Council, Inc., USA.
[7] Development of Piping Design Procedure Using CPSR (Constant-Pitch Span Rule), KOPEC/08-TD-8AF, by J. H. Lee and et al., December, 2008.
[8] Walter D. Pilkey, “Formulas for Stress, Strain, and Structural Matrices,” John Wiley & Sons, Inc., 1994.
[9] Crane Catalogue, Flow of Fluids through Valves, Fittings and Pipe, Technical Paper No. 410.