Geology and Geological Structure of Tsuruga Power Station Site

The D-1 Shatter Zone

Interim Report(No.2)

The Japan Atomic Power Company

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Contents

1. Introduction

Evaluation of the shatter zones in the site of Tsuruga Power Station(Tsuruga PS) has been discussed during the seismic back-check by the former Nuclear and Industrial Safety Agency(NISA) and the former Nuclear Safety Commission(NSC).

In the discussion of the seismic back-check, based on the opinions expressed by the former NISA during a field survey on the shatter zones in the site of Tsuruga PS conducted on April 24, 2012 and the instructions issued by the former NSC, we decided to implement a further geological survey in order to collect additional data.

Basic principles for the additional survey are indicated below and the survey work has been achieved after obtaining a survey plan approval from the former NISA at the occasion of the hearing about the earthquake and tsunami on May 14, 2012.

- Evaluation of activities of the shatter zones in and after the Late Pleistocene should be based on the evaluation by the overlying strata analysis method.
- If evaluation based on the overlying strata analysis method would be difficult, evaluations should be carried out in a comprehensive manner, based on the results of various geological surveys and numerical analyses.

The Nuclear Regulation Authority(NRA) was established on September 19, 2012, under which "Experts Meeting of the Survey(EMS) on Shatter Zones in the Site of Tsuruga Power Station" was formed (approved by the NRA on November 14, 2012). Then, a preparatory meeting was held on November 27, 2012, which was followed by a field survey conducted on December 1-2, 2012, the first EMS on December 10, 2012, the second EMS on January 28, 2013 and the third EMS and peer-reviewing on March 8, 2013.

In the last EMS, the report titled "Evaluation of Shatter Zones in the Site of Tsuruga Power Station of the Japan Atomic Power Company(JAPC: temporarily Draft) on March 8, 2013 (Tsuruga・peer 1-2)" (draft of EMS report) was submitted. The draft of EMS report refers to the evaluation of the D-1 shatter zone with saying "the shatter zones in the site of Tsuruga PS can be judged that it is highly likely to be an active fault which should be taken into account in the seismic design, based on the data obtained so far." Also, it adds, "if there would be new knowledge and findings in the future, this may be reviewed, if required."

The conclusion of the draft of EMS report was based on the major reasons described as the followings:

1. JAPC does not clarify the reasons for identifying the G fault as the D-1 shatter zone.

2. The shear of the K fault reaches bedrock and facing strata/um and thus it cannot be denied activities in and after the Late Pleistocene. This means that the K fault must be taken into account in the seismic design. [Data-1 to 4]

3. JAPC just clarified that activities of the D-1 shatter zone were older than about 7,300 years ago. [Data-5]

4. It is highly possible that the K fault is connected to the D-1 shatter zone because they have the same configuration (strikes and dips) and are closely located. [Data-6]

Judging in a comprehensive manner from the above, the EMS members tentatively have reached to a conclusion that the D-1 shatter zone is highly likely an active fault that should be taken into account in the seismic design and it can be moved with the Urasoko fault, which located at an extremely close range, and then the integrity of the safety related facilities of Tsuruga PS, just above the crash zone, would be affected.

On the other hand, JAPC has evaluated that the D-1 shatter zone would not be an active fault which should be taken into account in the seismic design based on the following understandings. The scientific bases for these understandings are written in the section 3.

① The D-1 shatter zone consisting of “cataclasite” and “fault gouge” runs almost in a North-South direction with a high-angle westerly dip. It has a good continuity.

② Through observation of thin section samples collected from the D-1 outcrop, drilling cores of ②-1 and B14-2 of the D-1 shatter zone, the all displacement senses of the last slip show a “normal fault” and a “right-lateral slip” sense.

③ Through observation of thin section samples and the observation result of the trench, the senses of displacement of the last slip of the G fault show a “normal fault” and a “right-lateral slip” sense.

④ Meanwhile, based on the displacement direction of the strata, the K fault shows a “reverse fault” sense. Also, through observation of slickenlines of the last slip, it is confirmed that the K fault consists mainly of “reverse fault” components.

⑤ Whereas both the G fault and the K fault could be seen as an extension of the D-1 shatter zone, it is judged that the D-1 shatter zone, which has a “normal fault” sense, would not continue to the K fault, but would connect to the G fault due to the same displacement sense.

⑥ Through observation of the strata at northern pit in the D-1 trench, it is confirmed that the G fault at least has not displaced or deformed layer①, which is located lower than layer⑤, which strata contains the Mihama tephra of 120,000 years ago.

⑦ Through observation of the strata at northern wall surface of the D-1 trench, it is clarified at least, that the K fault has not displaced or deformed the lower part of layer ⑤, which strata contains the Mihama tephra of about 120,000 years ago.

⑧ It is also observed that in the northern part of the western pit, the K fault changes the directions from N-S to NNW-SSE with bending. The shatter zone with N-S direction strick does not displace and deform layer ③ that covered the K fault in the south part from the bend.

⑨ In order to confirm whether the K fault extends to the south or not, the drilling core of B14-2, which is crossing between the Unit 2 reactor building and the K fault, has been investigated. As a result, the K fault could not extend to the south at least beyond the drilling of B14-2, since no observation of a "reverse fault" has been found in the drilling data.

⑩ Based on the above, the D-1 shatter zone continues not to the K fault but to the G fault and the D-1 shatter zone, including the G fault, cannot be an active fault that should be taken into account in the seismic design. In addition, the K fault is not an active fault that should be taken into account in the seismic design neither.

This report has been updated to the last interim report of JAPC dated Feb 5, 2013 by adding the current survey results obtained until the end of February 2013.

Major differences of views between the draft of EMS report and this report are shown in the [Data-7].

2. Geology and geological structure of the site

2.1 Contents of survey

In order to grasp the geological conditions and structure of the site, the following survey, analysis and other efforts were undertaken: [Data-8 to13]

- Bibliographic survey
- Tectonic landform survey
- Surficial geology survey
- Drilling survey
- Trench survey, pit survey
- Test tunnel survey
- Dating
- Observation of microstructures in fault shatter zone(*1) (*2)

*1) Kenichi Kano, Akihiro Murata, 1998, Structural Geology, Asakura-shoten.

*2) Takashi Nakajima, Hideo Takagi, Kazuhiko Ishii, Toru Takeshita, 2004, Field Geology 7 “Alteration/Deformation”, Kyoritsu Shuppan

The last slip of fault crash zone for the microstructure observation is determined from the structures cutting a whole shatter zone, considering the degree of linearity and softening of fault gouge. The way to prepare the thin section samples, which EMS pointed out not to be appropriate, would be taken into account for further observations and it will be confirmed that the current evaluation is valid.

2.2 Survey results

2.2.1 Geography of the site

The site consists mainly of a mountainous area. The well-dissected older fan surface is found mainly along the Wakasa Bay and the west of Urasoko Bay. The low terrace surface is found in a very small scale along the Wakasa Bay. The lowest terrace surface is found in the east coast of Urasoko Bay. The younger fan surface is found in a small scale in the downstream of a valley excavating mountains. The present river bed and talus are found in valley excavating mountains and the mountain slopes. The alluvial plane surface extends around the lowland around Urasoko Bay. The coastal plain surface consisting of beaches and beach ridges extends around. [Data-14]

The result of bibliographic survey suggests that there has been no document mentioning the existence of an active fault in the site, except the Urasoko fault. [Data-15]

Through aerial photo interpretation and others, as the existence of Urasoko fault is indicated by the documents, it is learned that there is a geography with a potential existence of tectonic landform in a direction of Northwest-Southeast (lineament), which runs through a boundary between the mountains and the lowlands that extend from Cape Tateishi to the west of Inogaike, consisting of steep cliffs, saddles, straight valleys and bending of valleys. On the other hand, the tectonic landform corresponding to shatter zones is not recognized.

2.2.2 Geology of the site

The geology of the site consists of Kojaku granite, dolerite that penetrates into Kojaku granite, and the overlying quaternary deposits. Kojaku granite is judged to be formed in the times between the late Cretaceous and the Paleogene, since the values range from some 66.6-64.2 Ma measured by potassium-argon dating. Dolerite is judged to have penetrated into during the Neogene Period (Miocene), since the values stand at around 21.1 Ma measured by potassium-argon dating. Adjacent to the lineament, the high-angle northeasterly dip fault (Urasoko fault) can be seen. The shatter zones with hydro-thermal alteration are found in Kojaku granite and dolerite.

Kojaku granite consists of biotite granite, granite porphyry and aplite. [Data-16, 17]

Analysis of a fault gouge by x-ray diffraction has found that the fault gouges in Kojaku granite on the Units 1 and 2 side as well as on the Units 3 and 4 side contain quartz, potassium feldspar, plagioclase, muscovite, kaolinite and smectite. Measured values of clay mineral by potassium-argon dating (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 54.6-61.4 Ma. The fault gouge in the Urasoko fault contains quartz, potassium feldspar, plagioclase, muscovite, kaolinite and smectite. Measured value of clay mineral by potassium-argon dating method (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 50.3 Ma. The fault gouge in dolerite contains high volume of smectite, medium volume of calcite and laumontite. Measured value of clay mineral by potassium-argon dating method (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 18.9 Ma. [Data-18]

2.2.3 Geological structure of the site

Many shatter zones are found in the site. The shatter zones found around the location of Units 1 and 2 run in the directions between N-S and NE-SW. Many of them are westerly dip. Some run in the direction of NW-SE with a northeastern or southwestern dip. Among them, the shatter zones running in the direction between N-S and NE-SW show good continuity. [Data-19 to 25]

The shatter zones found around the location of Units 3 and 4 run in the directions between N-S and NE-SW. Many of them are easterly dip. In dolerite adjacent to the Units 3 and 4, the shatter zones running in the direction of ENE-WSW are found, which have displaced the shatter zones running in the direction between N-S and NE-SW. [Data-26 to 29]

Among these shatter zones, those running in the directions between N-S and NE-SW are predominant. Also, the joints run in the directions between N-S and NE-SW, NNW-SSE and E-W. Among them, those running in the directions between N-S and NE-SW are predominant. As for dip, many of those adjacent to the Units 1 and 2 are high-angle westerly dips, while many of those adjacent to the Units 3 and 4 are high-angle easterly dips. [Data-30]

Regarding the Urasoko fault, to which the literature refers, drilling survey and trench survey have been conducted to understand the activity of the fault. Also, in order to know the location of fault extension in the southern area of the site, electrical exploration method and seismic reflection method were used.

As a result of survey, the Urasoko fault is judged as a highly straight line-type fault with an uplifting in the northeastern side between Kojaku granite and quaternary deposits. Urasoko fault has been active since Late Pleistocene and the latest event was at least after 4,000 years ago. [Data-31, 32]

Evaluation of the continuity of the shatter zones recognized by drilling survey, outcrop survey and trench survey has been undertaken in the following way: [Data-33]

① The identified shatter zones should be extended, following their strikes and dips.

- For strike and dip, values measured by a borehole television, surficial geology survey and test pit survey should be used.
- If there is no rational ground to bend it, it should be extended linearly in principle.

② If “a shatter zone that has similar strike and dip exists” and “a shatter zone whose strike and dip are unknown exists” in the extended location, it should be evaluated as being continuous.

- It should be deemed as being continuous on the assumption that a strike and dip change locally (changes in strike and dip are estimated within a range of ± 20°).
- In the case of the characteristics (whether a fault gouge exists or not, linearity, etc.) of shatter zones being different, if strike and dip are similar, it should be deemed as an extension and being continuous.
- If in the extended location “the existence of a shatter zone is unknown,” it should be extended directly.

③ In cases that in the extended location “the shatter zone is not identified,” and “a shatter zone with a different strike and dip exists,” it should not be extended further.

④ In case that in the extended location “the corresponding shatter zone is not identified and a different shatter zone is judged to cross,” it should be deemed that the shatter zones are consolidated.

3. Evaluation of the D-1 shatter zone

3.1 Contents of survey

The following surveys have mainly been carried out in order to clarify the continuity and activity the D-1 shatter zone:

- Drilling survey
- Outcrop survey
- Trench survey, pit survey

- Dating (Tephra analysis, Pollen analysis etc.)
- Observation of microstructures in fault shatter zone

Some of these surveys are still under investigation. Based on the results obtained so far, the D-1 shatter zone has been evaluated. Here, all the evaluations has been carried out by appropriate combinations of several survey methods such as drilling survey, trench survey and so on, depending on conditions of the D-1 shatter zones.

3.2 Survey results

3.2.1 Drilling survey

The D-1 shatter zone was identified at the drilling core of B6-5, B6-1 and B14-2 in the north of Unit 2 reactor building, and at the drilling core of 14, ②-1 and 2 in the south of Unit 2 reactor building. All of them consist of cataclasite and fault gouge. In general, they run in the direction of N-S and are high-angle westerly dip. [Data-34 to 36]

At the drilling core of ②-1, the direction of the shatter zone was not measured by a borehole television. At the drilling core of B14-2 and ②-1, observation of thin sections from fault gouge to know the displacement sense of the last slip reveals that it is a normal fault and has a sense of right-lateral slip. [Data-37 to 40]

In order to confirm whether the K fault extends to the south or not, the drilling core of B14-2 hole has been investigated whether a "reverse fault" sense as similar to the K fault exists or not, because the drilling B14-2 is crossing between the Unit 2 reactor building and the K fault,

In the data from the drilling core of B14-2, three parts of shatter zones have been found with fault gouge. The thin section sample observations have been carried out in order to confirm the displacement sense, where the one, the D-1 crash zone, has been cut along vertical and horizontal directions, and the other two parts have been cut along fault slickenline direction. As a result it is confirmed that all the last slip of displacement sense of the shatter zones has a normal fault sense.

Based on the above, it is judged that the K fault could not extend to the south, at least to the south beyond the drilling of B14-2. [Data-41 to 45]

3.2.2 Survey on the D-1 outcrop

Regarding the geological strata of the D-1 outcrop, the sedimentary layers are classified into layers A to C from upper to lower, based on the facies, and the basement rocks are classified into D to H based on the type of rocks and the degree of weathering. [Data-46]

Layer A is surface soil consisting of humic sand with gravels. Layer B is talus deposit with a high content of gravels. Layer C is talus deposit consisting of silty sand with gravels. D is relatively hard granite porphyry. E is softened granite porphyry, due to the hydro-thermal alteration or weathering, though a degree of shattering is low. F is cataclasite changed from aplite. G is softened aplite, due to hydro-thermal alteration or weathering, though a degree of shattering is low. H is basement rock, where the original rock texture is more ambiguous due to high degree of weathering.

As a result of tephra analysis, it is learned that layer A contains Aira-Tanzawa (AT) (about 27,000 years ago), while layer C contains both Aira-Tanzawa (AT) (about 27,000 years ago) and Kikai-Akahoya (K-Ah) (about 7,300 years ago). [Data-47]

The D-1 shatter zone consists with aplitic cataclasite and fault gouge, and runs in a direction of NNE-SSW with a high-angle westerly dip. Detailed observation reveals that the texture of gouge of the shatter zone is unclear, due to weathering in the upper part of rock mass. [Data-48]

Observation of the D-1 outcrop to know the displacement sense in cataclasite reveals that it is a reverse fault with a right-lateral slip sense. [Data-49, 50]

The thin section sample observation of block samples collected from the D-1 outcrop reveals that the displacement sense of the last slip is normal fault with right-lateral slip sense. [Data-51 to 53]

The results of observation of the D-1 outcrop and tephra analysis reveal that the shatter zone has not displaced or deformed layer C, which is the layer deposited after Kikai-Akahoya (K-Ah) (some 7,300 years ago).

3.2.3 Survey on the D-1 trench

The locations and numbers of trench survey should be determined based on the investigation objectives. The D-1 trench survey is aimed to make it clear if the D-1 shatter zone could move simultaneously with the Urasoko activities, and thus the trench survey has been carried out basically in the location close to the Urasoko fault. To determine the locations and numbers of trench, the restrictions of space and/or interferences to existing facilities were also taken account.

Regarding the geological strata of the D-1 trench, the sedimentary layers overlying granite porphyry are classified into layers ① to ⑨ from lower to upper. [Data-54 to 57]

Layer① consists of very tight, poorly sorted sand gravels. Layer② consists of block-shaped, tight sandy silt and silty sand, and also contains lots of decayed gravels. Layer③ consists mainly of sand gravels, to which lens-like or layer-like silt layers and sand layers are inserted. This layer contacts with unconformity surface denuding lower layer. Layer④ is a belt-like oxidized portion on the top of layer③. Layer⑤ consists mainly of silty sand gravels and contains non-continuous alternate layers of silty sand gravels and silt. This layer can be segmentalized into the upper and the lower parts depending on the differences of sedimentary structures. The lower part shows the layer thickness has been decreased along the west direction of the north wall, but the thickness has been increased along the east direction. And this increase becomes strong as close to the Urasoko fault, since the basement line tends to be lower as close to the Urasoko fault. The upper part shows rather horizontal line and a constant thickness. The lower part erodes the lower layer greatly and it contacts with the layer in the unconformity surface. Layer⑥ consists of humic sandy silt and silty sand, and also contains lots of wood chips. Layer⑦ consists of sandy silt with gravels and silty sand with gravels. Layer⑧ consists of sand gravels with silty sand, and partly has stratified structures. Layer⑨ consists of sandy silt with gravels. From layer① to the upper part of layer⑨ are cut off by Urasoko fault.

The result of tephra analysis reveals that the upper part of the layer⑤ contains the Kikai-Tozurahara (K-Tz) tephra horizon.

A tephra consisting of hornblende was detected from the lower part of layer⑤. The tephra can be correlated to Mihama-tephra from the comparison of refractive index and ingredient components. According to Yasuno (1991) (*3), Mihama-tephra is located in the lower part of middle terrace marine deposit, which is under Sanbe-Kisuki (SK) tephra (about 110,000 – 115,000 years ago [Atlas of tephra in and around Japan (*4)]).

Based on the above, it is judged that the lower part of layer⑤ is equivalent to marine oxygen-isotope stage 5e.

In the tephra analysis of multiple measurement line, the tephra consisting of hornblende has an lower occurrence limit in the almost same horizon, there is no reverse of depositional age including other tephras, and the lower occurrence limit is located above the unconformity between layer③. Therefore the lower part of layer⑤ is judged to be a horizon of Mihama-tephra. [Data-58 to 59]

*3) Yasuno. T, 1991, Discovery of Molluscan Fossils and a Tephra Layer from the Late Pleistocene Kiyama Formation in West of Fukui Prefecture, Central Japan, Bull. Fukui Mus. Nat. Hist., No.38: 9-14

*4) Machida. H, Arai. F, 2003, Atlas of Tephra in and around Japan, Univ. Tokyo Press, Tokyo.

(1) About the G fault

The G fault is recognized at the northern pit of the D-1 trench, which is located on the line extended from the D-1 shatter zone. The G fault consists of granite porphyry cataclasite and yellow brown fault gouge and has strike in a direction of N-S and high-angle westerly dip. [Data-60, 61]

From the thin section observation of a block sample at the south of the northern pit, the displacement sense of fault gouge of the last slip has normal fault and right-lateral slip sense. [Data-62 to 64]

The G fault, which is recognized at the northern pit of the D-1 trench, has not displaced or deformed layer①, which is located under layer⑤ (a layer including Mihama-tephra about 120,000 years ago). At the southern pit, a shatter zone also has not displaced and deformed layer①. [Data-65, 66]

(2) About the K fault

The K fault is recognized in the deposit at northern wall surface of the D-1 trench. Due to the displacement of the strata, the K fault has reverse-fault sense.

At the northern wall surface of the D-1 trench, the northern part of the K fault is recognized in layer③, which is located under layer⑤ (a layer including Mihama-tephra about 120,000 years ago). The northern part of the K fault has a strike in a direction of N-S and westerly dip. The northern part of the K fault terminates in layer③ and is covered by the upper part of layer③. Southern part of the K fault changes its strike direction to NNW-SSE around western pit. The southern part of the K fault has westerly dip and terminate in layer③. [Data-67]

At L-cut pit, the K fault is recognized between decayed granite porphyry and layer②. Strike and dip is a direction of N-S and high-angle westerly dip consisting of fracture segment of gray fault gouge with hydrothermal alteration. There is no linear fault gouge in the shatter zone. From the geologic observation, the K fault is a reverse fault with right-lateral slip and the relative elevation of the basement rock is about 1.8m. [Data-68, 69]

From the observation of block sample, the K fault (N-S strike part) found at L-cut pit is judged to mainly have reverse fault components, because the slickenline direction of the last slip is 80 degrees R. [Data-70]

At the northern widening part of western pit in the D-1 trench, the K fault that has displaced layer③ curves in the pit and changes its strike direction from N-S to NNW-SSE. The shatter zone with N-S direction strike does not displace and deform layer③ that covered the K fault in the south part from the bend. [Data-71 to 74]

3.3 Evaluation of continuity and activity of the D-1 shatter zone

3.3.1 Continuity of the D-1 shatter zone

The continuity of shatter zone has been evaluated based on the concept of evaluating continuity described in “2.2.3 Geological structure of the site.”

The data used for the evaluation of continuity are as follows:

- North of Unit 2 reactor building: The D-1 trench: Northern pit, Western pit, L-cut pit
  Survey drilling: B14-2, B6-1, B6-5
- Unit 2 reactor building: Survey of test pits: Pit A, Pit B, Pit C, shear test pit
- South of Unit 2 reactor building: Survey drilling: 14, ②-1, No. 2, the D-1 outcrop

The shatter zones recognized as the D-1 shatter zone run almost in a direction of N-S with high-angle westerly dip, and have excellent continuity. All consist of cataclasite and fault gouge with a sharply-defined brown colors.

The D-1 shatter zone and the G fault have the sense of normal fault from the observations of displacement sense, and the K fault changes the direction from N-S to NNW-SSE within the western pit of the D-1 trench, the K fault has the sense of a reverse fault and the K fault does not extend to the south at least beyond of the drilling B14-2. According to these facts, the K fault would be different from the D-1 shatter zone and that the G fault and the D-1 shatter zone compose of a series of shatter zones. [Data-75]

3.3.2 Activity of the D-1 shatter zone

In the outcrop of the D-1, the D-1 shatter zone has not displaced or deformed layer C, which was deposited after Kikai-Akahoya (K-Ah) (about 7,300 years ago). Also, at the northern pit of the D-1 trench, the G fault has not displaced or deformed layer①, which is located lower than layer⑤, which contains Mihama-tephra which is at least 120,000 years ago.

The K fault has not displaced or deformed at least the lower part of layer⑤, that contains Mihama-tephra which is at least 120,000 years ago, in the north wall of the D-1 trench.

Therefore, the D-1 shatter zone including the G fault was not active at least in and after the Late Pleistocene. In addition, the K fault was not active at least in and after the Late Pleistocene.

3.4 Evaluation of simultaneous activities of the D-1 shatter zone and the Urasoko fault

The simultaneous activities of the D-1 shatter zone and the Urasoko fault have been investigated based on their respective history of activity and from a dynamical point of view.

3.4.1 Investigation on history of activity

The most recent activity of the Urasoko fault took place no earlier than about 4,000 years ago and the mean recurrence is 5,000 years ± 2,000 years(Source: the National Institute of Advanced Industrial Science and Technology, et al. 2012(*5)), while the D-1 shatter zone has not been active at least for the past 120,000 years. This has led to the assumption that the Urasoko fault had moved over 10 to a couple dozen of times for the past 120,000 years. But, during this period, the D-1 shatter zone has never moved. Also, as no view has been expressed about the change of regional stress field since the Late Pleistocene, it is judged that the Urasoko fault and the D-1 shatter zone will not move simultaneously in the future.

*5) Survey on active faults in coastal zones; Yanagase and Sekigahara fault zones; Urasoko-Yanagase fault belt; Report of Results; May 2012; the National Institute of Advanced Industrial Science and Technology & Tokai University; p33.

Concerning with activity of Urasoko fault, JAPC currently performs additional survey on geography and geology from the view point of simultaneous activity of some active faults around the site of Tsuruga PS.

3.4.2 Study from dynamical point of view

In the evaluation of fault displacement caused by earthquake, “Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities” (December 20, 2010, approved by the NSC) mentions the necessity of evaluating displacement and deformation due to the fault displacement, by numerical analysis, developed on the ground where buildings and other structures are located.

Based on this Guide, the numerical analysis has been carried out in order to clarify whether displacement may occur or not in the nearby shatter zones including the D-1 shatter zone, due to the activity of the Urasoko fault.

By numerical analysis, the bearing capacity of the grounds, containing the D-1 shatter zone in association with the activity of the Urasoko fault, has been evaluated. As for the stability evaluation of shatter zones, the local safety factors that was estimated by FEM analysis have been employed. [Data-76, 77]

In numerical analysis, first we performed analysis of the ground deformation based on the "elasticity theory of dislocation" with assuming that the ground is semi-infinite elastic medium, and then performed "basic study" and "study taking uncertainty into account," thus drawing up conditions for computation that would produce the severest results in evaluation of bearing capacity of the foundation ground of the Unit 2 reactor building. Then, based on such conditions, we performed analysis, using a Finite Element Method (FEM) model which is an in-depth model of the ground.

3.4.2.1 Elasticity theory of dislocation

(1) Objective

Based on the elasticity theory of dislocation, we studied vertical displacement (inclination) and horizontal deformation (horizontal shearing strain) to be caused by the activity of the Urasoko fault at the location where the Unit 2 reactor building stands.

As for the analytical conditions, the procedure of the Tsunami Evaluation Method (Tsunami Evaluation Subcommittee, Nuclear Civil Engineering Committee, Japan Society of Civil Engineers, 2002(*6)) is employed as a reference.

*6) "Tsunami Evaluation Method for Nuclear Power Plants," 2002, Tsunami Evaluation Subcommittee, Nuclear Civil Engineering Committee, Japan Society of Civil Engineers

In the analyses, the uncertainties of several parameters such as length of fault, angle of dip, width of fault, and so on have been taken into account.

(2) Inclineation of ground where Unit 2 reactor building stands

The case of p-axis = 90° that represents the maximum dip in the primary analyses, has been carried out with uncertainties. As a result, a dip becomes maximum, when the length of fault, i.e., the position of northern end of fault, is set near the reactor building. [Data-78]

(3) Deformation of ground where Unit 2 reactor building stands

The case of p-axis = 115° that represents the maximum horizontal shear strain in the primary analyses, has been carried out with uncertainties. As a result, a horizontal shear strain becomes maximum, when the length of fault, i.e., the position of northern end of fault, is set near the reactor building. [Data-79]

3.4.2.2 FEM analyses

By using the severest conditions, which are drawn up from the evaluation of bearing capacity of the foundation ground of the Unit 2 reactor building, a Finite Element Method (FEM) analysis has been examined based on the “elasticity theory of dislocation,”. In production of the FEM model, non-homogeneity and non-linearity of the geography and the ground were taken into account to reflect the results of existing geological surveys and tests on the physical property of the ground.

(1) Vertical two-dimensional FEM analysis

In the result of study based on the “elasticity theory of dislocation,” a vertical two-dimensional analysis has been achieved in order to give the maximum a dip at the location of the Unit 2 reactor building. The location of section used for analysis was set as vertical plane perpendicular to the reactor building (B-B’ section), which is an almost vertical plane perpendicular to the Urasoko fault.

As a result of analyses, developments of shear failure and tensile stress are estimated in the shatter zone near the Urasoko fault. But, as such area is limited and the local safety factors near the reactor building show sufficient safety margin, the ground would have enough bearing capacity. [Data-80]

(2) Horizontal two-dimensional FEM analysis

In order to make an in-depth study on an effect of strike slip of fault, in the result of study based on the “elasticity theory of dislocation,” a horizontal two-dimensional analysis has been achieved in order to give the maximum horizontal shearing strain at the location of the Unit 2 reactor building. The location of topographic profile used for analysis was set at the level of the Unit 2 reactor building (T.P.-15.0 m).

As a result of analysis, developments of shear fracture and tensile stress are estimated in the shatter zone near the Urasoko fault. But as such area is limited and the local safety factors near the reactor building show sufficient safety margin, the ground is would have enough bearing capacity. [Data-81]

3.4.2.3 Summary

Evaluations of bearing capacity of the grounds have been carried out including the D-1 shatter zone, in relation to the activity of the Urasoko fault by numerical analysis. As a result, developments of shear failure and tensile stress are estimated in the shatter zone near the Urasoko fault, but such area is limited and the local safety factors near the reactor building show sufficient safety margin. Thereby, it is confirmed that the ground has enough bearing capacity against the activity of the Urasoko fault.

Based on the above understandings, the D-1 shatter zone is judged not to be displaced by the activity of the Urasoko fault.

3.5 Overall judgment

Based on the facts of the crossing route, characteristics, strike and dip of the D-1 shatter zone, and the displacement sense of the last slip showing normal fault and right-lateral slip sense, the D-1 shatter zone located just beneath the Unit 2 reactor building would continue to the G fault at the northern pit of the D-1 trench. In addition, it is confirmed by using the overlying strata analysis method at the northern pit of the D-1 trench that the D-1 shatter zone has not displaced or deformed layer① which is located lower than the lower part of layer⑤ which is a strata containing Mihama-tephra about 120,000 years ago.

Also, as the tectonic landform corresponding to the D-1 shatter zone was not recognized by the tectonic landform survey, and the displacement sense of the last slip in the shatter zone shows a normal front sense, it is judged that it was not formed by the present regional stress field, which could be produced through East-West compression.

Moreover, in the light of activity history and dynamics, it is judged that the D-1 shatter zone would not be displaced in conjunction with the activity of the Urasoko fault.

Therefore, the D-1 shatter zone is not an active fault that should be taken into account in the seismic design.

By applying the overlying strata analysis method, it is confirmed that the K fault has not displaced or deformed at least the lower part of layer⑤, that contains Mihama-tephra which is at least about 120,000 years ago, in the north wall of the D-1 trench.

In addition, in order to confirm whether the K fault extends to the south or not, the drilling core B14-2, which crosses between the Unit 2 reactor building and the K fault, has been investigated. As a result, the K fault could NOT extend to the south at least beyond B14-2, since no observation of a reverse fault has been found in the drilling core data.

Based on these facts, the K fault is not an active fault and should not be taken into account in the seismic design. [Data-82]

Lastly, the distribution of the K fault and its genesis are still under investigation, and thus the result will be reported after examination. [Data-82]