Comments on the shatter zones in the site of
Tsuruga Power Station owned by The Japan Atomic Power Company
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I visited Tsuruga Power Station (Tsuruga PS) on March 30, 2013 in cooperation of The Japan Atomic Power Company (JAPC) to observe the active fault, shatter zones and related quaternary system in the site of it. I report here the discussion result on the characteristics, continuity and activity of the fault and shatter zones, together with the investigation results summarized as an interim report by JAPC. It is necessary to confirm the results shown below on the structural geological observations including micro structures of the shatter zones through conducting an investigation in detail by tectonic geologists.

1. Structures and continuity of D-1 shatter zone
[Summary] D-1 shatter zone observable on the outcrop just south of Tsuruga PS Unit 2 shows common characteristics with D-1 shatter zone previously described. The comprehensive observation and description of major shear plane with fault gouge and shatter zone structure supports it.

- ✓ Apparent fault plane is single shear plane of N20°E strike and steep westward dip, where white fault gouge with 1—10mm thickness are bordered by black bands with 0—5mm thickness. Joints of NS and N20°E--30°E strike developed with several cm pitches in the cataclasite zones with around 1 m thickness at both sides of the shear plane construct the shatter zone. The shear plane with fault gauge juxtaposes granitic rocks of different color and texture, indicating significant amount of slip. Slip direction was unclear by the outcrop observation.

- ✓ Shear plane described as D-1 shatter zone or considered continuous to it in the investigations to date has closely NS or N20°E--30°E strike. This strike is consistent with that of the shear plane and joints observed in the outcrop mentioned above. It is estimated that the network shear plane system structure of major shear plane with NS strike is connected by N20°E--30°E striking oblique shear planes.

2. G fault characteristics and continuity to D-1 shatter zone
[Summary] The G fault in the North pit of D-1 trench and the D-1 shatter zone on the outcrop just south of Unit 2 are identical for their macroscopic structural characteristics. This indicates the possibility that they had been formed at the same time in the location under a unique geologic environment.

- ✓ G fault on the bottom of the north pit in D-1 trench is a distinctive shear plane of NS strike dipping steeply to west, and yellowish white fault gauge with 1--10 mm thickness accompanies black bands with 5—10mm thickness on the east side. Joints of NS and N20°E--30°E strike developed with several cm pitches in the cataclasite zones with around 1 m thickness at both sides of the shear plane construct the shatter zone. The shear plane with fault gauge juxtaposes granitic rocks of different color and texture, indicating significant amount of slip. Though the slip direction was unclear by the outcrop observation, displacement of the shear plane had a horizontal component because a dragging structure was observed in the fault gouge on the bottom surface of North pit.

- ✓ Fault gouge and black bands of G fault are very similar to those of D-1 shatter zone on the outcrop south to Unit 2. Here at G fault, major shear plane with NS strike is formed in the system of joints with N20°E--30°E strike and dip identical to those of D-1 shatter zone. This is also common characteristics with D-1 shatter zone observed to date.

- ✓ The fault gouge on the bottom surface of north pit in D-1 trench is distinguished in color from those of the other D-1 shatter zone. It shows the color from yellowish white to orange-white, owing to weathering by dissolved oxygen in ground water. The fault gouge observed here is located just below the plane of unconformity between gravel layers and granite of later Middle Pleistocene. This spot was located on the base of gravel layers about 20m from just below river bed from Middle Pleistocene to Late Pleistocene, and much ground water was flown. It was obvious that the ground water existed because manganese deposited caused by ground water along with the joints of granite. It seemed that weathering of fault gouge and iron oxide deposit were promoted by oxidizing atmosphere.

3. K fault in D-1 trench

[Summary] K fault seemed to be cyclically active in shallower underground with fewer times slip based on configuration and characteristics of the fault plane. K fault has the characteristics different from that of D-1 shatter zone and G fault, and seems not continuous fault acting with D-1 shatter zone and G fault at the same time.

- ✓ K fault cutting the bedrock in 2-1 pit contains a very five material with 1--2 mm size like fault gauge along the shear plane, but there are no joint formation and no brecciation related to the shear plane. Deformation and shatter extent around fault gouge and fault plane is almost negligible compared with D-1 shatter zone, G fault and the other shatter zones near Urasoko fault.

- ✓ Around the specific portion with strike close to NS, cracks are found with strike close to the joint system accompanied by G fault, but the density of those cracks are much lower than that of D-1 shatter zone. Cracks thinly found around the portion with changing strikes from NS to SE, that seem to be the fracture due to the change of strike, are formed independently on the system of joints accompanied by G fault.

- ✓ K fault is bifurcated, gets lower-angle dip in sediment and is covered by the upper layer No.3. Since getting lower-angle of dip is a generally observed phenomenon for reverse fault that crosses unconsolidated sediment in shallow ground, therefore it was obvious that K fault was active at last while the layer No.3 was deposited.

- ✓ The thickness of sand gravel and silt layers at the upper end of K fault differs across the fault. It means that fault slip contains the strike slip component. However, it is estimated that the strike slip component is smaller than the reverse fault component. The major reason of the estimation is that the sand gravel and silt layer generally corresponds across the fault and the difference of layer thickness is little, though the sand and gravel layer has strong lateral change with channel and point-bar deposit. Also, some little extent of strike slip component is inevitably induced because the strike differs so sharply from SN to NWSE in a small area with 10m and a little more width. It is necessary to examine slip vector components in detail in order to consider strike slip component strictly.

- ✓ The strike change and discontinuity to SW direction implies that a compression stress field distributed locally (in the order of 10m) along Urasoko fault, that might have produced reverse fault and strike slip deformation. Irregular shape of Urasoko fault is considered to be a cause of forming such a local stress field. When a irregular shape such as compressible jog, kink or salient and so on existed on the fault plane of Urasoko fault that had a strike slip component, a local stress field was produced in a local range related to the size of the irregular shape. Some local stress fields change position due to the advance of the strike slip.

- ✓ The observation that a fault without a series of joints or fault breccias had some a little times activation cycle only within the shallow ground, can be reasonably addressed that a compressive stress field was temporally created and disappeared in this position along Urasoko fault. The fact that the displacement by one-time slip observed in the layer No.3 (order of 10cm) was one-order smaller or less than that of Urasoko fault was consistent with the characteristics of collateral derivation fault.

- ✓ The structure of K fault has no relation to that of D-1 shatter zone in the section where the strike tends to the west, tough a part of reverse fault that curves like a bow has identical strike and dip to those of D-1 shatter zone.

4. The latest activation age, slip sense and stress field of fault and shatter zone

[Summary] K fault has no relation to D-1 shatter zone as mentioned above. It is reasonable to consider that D-1 shatter zone had not had any activation histories in the Quaternary, unless the evidence of activation of D-1 shatter zone as the west-side raised reverse fault will be shown at D-1 shatter zone itself.

- ✓ Compressive stress field along east-west direction exists under Tsuruga peninsula and its around based on observations of Urasoko fault and the other faults around.

- ✓ Possible slip that can happen in D-1 shatter zone with SN strike and westward dip should not be any patterns but reverse fault slip. However, the principal component would be reverse fault component and the strike slip component would be a little, though oblique slip could be generated because the compression axis of stress field is not just aligned to east-west direction.

- ✓ However, only normal fault slip accompanied with right-lateral slip has been observed from the deformation structure of D-1 shatter zone. Any latest slips with reverse fault component should be recorded in superscript. If a right-lateral slip alone occurred in latest, then the motion should be recorded, too. The fact of no such records having been found yet shows that D-1 shatter zone have not had any slips in latest (in late Quaternary).

5. Activation age and activity

- ✓ It is certain that the base of layer No.5 is a irregular shape plane prior to last interglacial from sedimentation rate estimated based on the stratigraphic position of DKP and KTZ with deducing the thickness of wood peat. The existence of amphibole considered originated from Mihama tephra above the base of layer No.5 is harmonic with the estimation based on sedimentation rate. In this case, the formulation age of the irregular shape plane should be MIS 6.

- ✓ It is estimated that Urasoko fault, K fault and D-1 shatter zone have never simultaneously activated, because K fault has no relation to D-1 shatter zone and D-1 shatter zone had not had any activation histories in the Quaternary as mentioned above. Thus, we should consider whether the motion of Urasoko fault in the future will not induce slip of D-1 and the other shatter zones. For this purpose, it is not enough to collect geological evidences in the past. It is necessary to examine the possible fault slip based on dynamic, mechanical simulations. It is an important issue to investigate shear strain, stress concentration, deformation, and so on, based on the distance from elastic analyses and FEM computations, as performed in seismic back check. Also, the influences of Urasoko fault motion on important facilities of Tsuruga PS should be checked by similar evaluation methods. Since such methods developed at first in seismic back check have many challenges to improve, it is desirable to develop more those evaluation methods in the investigation this time.