HALL OF FAME

A Pioneer of Computational Welding Mechanics and Ultimate strength analysis (ISUM)

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Brief Citation

Yukio Ueda was born in 1932, Osaka, Japan and he graduated from Osaka University. There he served as a professor from 1975 to 1996 and also was the director of Welding Research Institute from 1992 to 1996. He is Professor Emeritus of Osaka University. He received Ph.D. from Lehigh University, U.S.A. in 1962 and Dr. of Engineering from Osaka University in 1968. He was awarded Honorary Doctor from Norwegian University of Science and Technology, Norway in 2002.

In 1971, Dr. Ueda published an English paper with his a graduate student, in which they developed a computational method for the thermal elastic-plastic analysis of metals during welding with the aid of the FEM. This paper opened the door to the research area of computational welding mechanics. For this pioneering contribution, they received the best paper award from the JWS （Refer to the abbreviation） in 1973. He and his colleagues presented several basic analysis methods for welding residual stress produced in various joints such as a butt joint of two long plates under a moving heat source, multi-pass welded butt joint of thick plates, etc. and clarified the producing mechanism of complicated welding residual stresses. Additionally, the method of reducing residual stress and the mechanical conditions of weld cracking were elucidated.

At the same time as extending the basic methods, he discovered the new capability of inherent strain theory and succeeded in measuring three-dimensional welding residual stresses in thick plates, fillet welds, etc. for the first time in the world, and predicting welding residual stress and deformation in large structures. For his pioneering and outstanding achievements in the field of computational welding mechanics, he received The Scientific Engineering Prize from the Society of OMJSPW in 1993, the Academic Contribution Award from the JWS in 1995, and later the IIW Arata Award for his outstanding achievement in fundamental research in 2000 from the IIW. He served as a member of the Technical Committee, an advisory body on technical issues handled by IIW from 1991 to 1999.

In connection with this, Dr. Radaj published a book on Welding residual stresses and distortion, Calculation and measurement, from DVS-Verlag and depicts on its inside front page that “Dedicated to Yukio Ueda and John Goldak, Pioneers of Computational Welding Mechanics” in 2003. To further develop the achievements of these two pioneers, the Pioneers Award was set up within the International Conference of Welding Science and Engineering (WSE) in 2011.

Thus, he established the framework of the computational welding mechanics. At present, the computational welding mechanics is a dispensable tool.

In the construction stage of ship structures, many curved plates are manufactured. This work is mostly dependent upon the skill of well-trained craftsmen for plate bending by line heating. To solve the problems associated with today’s decrease of such craftsmen and the demand for high efficiency, one of the measures is to promote mechanization of the procedure. To solve this problem, Professor Ueda and his collaborators applied an inverse analysis method based on the inherent strain method to theoretically elucidate this work and realize its mechanization for automatic forming. For this striking invention, they received the invention award from the SNAJ in 1999 and the JSPMI Award in 2001.

Prof. Ueda had such design concept as that the scantlings of individual structural members should be determined ideally after their functions should have been clarified observing the entire process to the overall collapsing state and this results in refining the safety evaluation of large structures. In order to realize this concept, he proposed with his graduate student a new computational method: ISUM (Idealized Structural Unit Method) for the ultimate strength analysis of structures. This analysis method embodies the engineering and innovative idea of idealizing and analyzing the nonlinear behavior of structures. They received the best paper award from the SNAJ in 1974. He and his colleagues developed several ISUM elements and illustrated successfully the possibility of analyzing the ultimate strength behavior of ships and frame structures with a very high speed maintaining reasonable accuracy.

While expanding the ISUM analysis method, he with colleagues developed the new elastic-plastic analysis method for the finite element method, which is named as Plastic Node Method by concentrating plastic zones into the nodal points of various finite elements such as rods, plates, and solid blocks. This method was further extended to deal with strain hardening, large deflection and cyclic hardening effects and applied to the collapse analysis of offshore framed structure under dynamic cyclic loadings. He and his colleagues developed analysis methods not only for static ultimate strength of offshore structures, but also dynamic behavior under collision considering oil rig-water and ship-water interactions. They received the outstanding paper award from OMAE in 1990 and the best paper award from ISOPE in 1992.

In 1997, at the Occasion of the Centennial Celebration of the SNAJ, the Great Longtime Contribution Award and the Shipbuilding Technology Award were conferred to him also from the SNAJ in 1998.

For his contributions and achievements in these two research disciplines, he is recognized as a pioneer.

He served as Editor of International Journal of Marine Structures and Associate Editor for Applied Mechanics Reviews ASME, OMAE and ISOPE. Professor Ueda was the chairman of the Japanese Technical Committee of DNV.

During the time for preparation of this citation, it was realized that his most basic, key papers were written between his ages of 35 and 45 for 10 years after returning from Lehigh University, U.S.A. During this 10 years, his capable colleagues were mostly Ph.D. graduate students. He published about 450 research papers before retiring from research.

1 From birth to studying abroad (1932~1962)

Professor Yukio Ueda was born as the first son of his parents on April 12, 1932 in the city of Osaka, Japan. His father ran a rice- grain business. His parents were from Nara Prefecture where is bordered by Osaka prefecture.

From 1936 to 1939, he attended Public Kindergarten in Osaka. In succession, he attended Public Elementary School and was awarded Academic Excellence Award every year (1939~1944) and recognized as a model student.

His father convened to the Army during World War II and returned to home due to illness. In 1944, he and his sister, elementary school children, were evacuated by state order to protect them from war raids to the countryside of Nara Prefecture. He transferred to a relocated primary school (1944~1945). His father died of illness in 1945. His family became mother and one sister. In August, 1945, World War II was over. The living environment after the war was very harsh. Especially the food situation was very severe.

In 1945, he entered into Nara Prefectural Unebi Middle School and was awarded a student with excellent grades during his school years. In 1948, Japanese education system changed. Then, he went to Nara Prefectural Unebi Senior High School. He returned to Osaka again with his family.

In 1951, he entered Osaka University, majoring in Naval Architecture and obtained B.S. He subsequently entered the graduate school and received MS degree in 1957. In the same year, he was hired as a research assistant. He participated in a research project on the contribution of superstructure to hull strength. The project leader applied the variational principle to the theoretical analysis. The experience with this research project had significant implications for his subsequent research life.

In 1959, Prof. Terazawa (Head of research division) gave him the opportunity to study the plastic design of steel structures at Lehigh University, U.S.A. He was admitted in the graduate school and awarded Ph.D. in Civil Engineering in 1962. At Lehigh, he was hired as a research assistant and later associate from 1960 to 1962.

He carried out a research for his PhD dissertation, whose title was “Elastic, Elastic-Plastic, and Plastic Buckling of Plates with Welding Residual Stresses” (1, 2). The research consisted of theoretical analysis and experiments. The result of theoretical analysis using the deformation theory showed good correlation with the experimental ones. The study of his Ph. D. dissertation had a major impact on his subsequent research career. That is, his research themes were limited to the following two: (1) Elastic-plastic buckling and collapse, and (2） Welding residual stress and deformation.

On the way back home from Lehigh University, he visited several universities. At the University of Michigan, he met Prof. Bruce Johnston, who was an authority in buckling of structural elements. He said, “As we have no such excellent testing machines as Lehigh has, I perform my research with aid of numerical analysis that is Numerical Simulation”. The second meeting was with Prof. R.W. Clough at U.C. Berkeley, and he showed him the result of comparison between a new method of numerical analysis and experiments on plate bending under distributed loads. A few years later he noticed that this new computational method was the Finite Element Method and Prof. Clough is one of its pioneers.

2 Beginning of Research life

In 1962, he became a lecturer at Osaka University. From 1963, a few graduate students joined his research group every year.

In 1965, Prof. Washizu (Tokyo Univ.) launched a study group on the Finite Element Method in Japan, marking the dawn of that era. Ueda became a member of the new committee. He started research using the finite element method with graduate students. In the middle of 1960’s, they had to use very preliminary computers in the university, whose capacity was small and speed very slow. It took them a few days to one week for one turn-round of computation developing a homemade computer program.

In 1968, he was awarded Dr. of Engineering from Osaka University, and promoted to Associate Professor. In 1969, he presented papers on the analysis of El-Pl Buckling of Plates by Finite Element Method [3] and New Theory on Elastic-Plastic Analysis of Framed Structures [4].

In 1969, a Japan-US seminar on FEM was held in Tokyo, and so in 1972 in Oakland, USA.

In 1971, he was transferred to newly established Welding Research Institute (JWRI), Osaka University, and in 1975, he was promoted to Professor of Research Division of Elasticity and Plasticity.

His two main research themes were as follows: (1) Analysis on thermal elastic-plastic stress-strain of metal during welding. This evolved into computational welding mechanics.

(2) Elastic-plastic buckling analysis of a rectangular plate. This evolved into ultimate strength analysis of structures, which is ISUM (Idealized Structure Unit Method). In order to write the detailed development of his research, the above two research fields will be dealt separately.

Being engaged with the research, he was also involved in the university administration as follows: He was a member of University Council, Osaka University from 1982 to1984. He was elected Director of Welding Research Institute in 1992 and performed a reorganization and renaming of the institute. The name of the institute changed to Joining and Welding Research Institute (JWRI). In1996, he retired from Osaka University and was appointed Professor Emeritus. He continues to be a professor of Kinki University, Japan and participated in the establishment of a new department at School of Biology-Oriented Science and Technology. In the following year the new department: Mechanical Engineering was founded and became the chairman. The goal of this new department was to promote education and research on biomimetic, universal design and robotics based on ergonomics.

3 Research life on Computational Welding Mechanics (1963~2003)

3.1 Analysis of welding stress and strain

Before the 1960s, research on welding mechanics had been carried out basically by experiments and elastic analysis [5, 6]. Because of the complex and non-linear nature of welding phenomena, welding mechanics is an interdisciplinary research field involving temperature-dependent metallurgical changes and elastic-plastic mechanical properties of materials in accordance with changes in heat transfer of the welding heat source. In order to mitigate the complex nature of the nonlinearity of welding mechanics, the small effects of coupling between temperature and stress-strain fields may be disregarded. With this assumption, the analysis of the heat transfer problem and thermal stress-strain analysis can be dealt independently.

In 1971, Professor Ueda developed a computational method for the thermal elastic-plastic analysis of metals with the aid of the FEM with a graduate student, Yamakawa.

Firstly, the method was applied to one of the typical examples of welding work that is butt-joining two long steel plates. The transient temperature and thermal stress-strain distributions of a butt welded joints were computed from the beginning to the end of the welding under a moving heat source, taking into account the effect of the temperature-dependent properties of materials. The computed results were proven reasonable by showing good accordance with the geometries of the molten pool, heat-affected zone, the pattern of residual stress distributions which were observed in actual welded joints. Based on the results, an English paper; Thermal Elastic-Plastic Analysis of Metals during Welding, was published in Transactions of the Japan Welding Society (JWS) [7] in 1971 and submitted also to the International Institute of Welding (IIW). This paper is regarded as one of the earliest publications on this subject in the world and was given the best paper award from JWS [Award 1].

Another typical manufacturing subject by welding is cold cracking at the first pass of a butt welded joint. Cracking occurs when the stress strain generated by restraining shrinkage during the cooling process reaches a certain value, being subjected of the influence of diffusible hydrogen.

The RRC (rigidly restrained cracking) test examines the possibility of weld cracking at butt weld joint under a specified intensity of external restraint maintained in the entire course of welding, and the relation between the intensity of restraint and the possibility of crack initiation can be found by performing a series of tests for different degrees of intensities. The analysis was carried out to clarify how local stress/strain is produced in a typical RRC test specimen of mild steel, whose length was 200 mm. According to the experiment, the specimen of 200 mm length showed weld cracking. In the early stage of the cooling process, the local stresses at the upper and lower corners of the weldment were tensile and compressive, respectively. In the final stage of the cooling process, heat is released to the outside, causing shrinkage of the entire test specimen, which is suppressed and a large tensile force is induced in the entire specimen. In this case, the weld cracking would initiate at the lower corner of the weldment where the largest tensile plastic strain was produced [8].

The analysis method was extended to apply for stress-relief annealing taking into account of creep properties of material [9] in 1977 with Fukuda.

Primary structural components in power generators are manufactured by joining thick plates by multi-layer welding. Ueda challenged to apply this analysis method to multi-pass welded joint of thick plates with Fukuda. The welded joint studied was a butt welded joint of 150 mm thick steel (ASTM A336F22; 21/4Cr-1Mo) plate built up by 30 passes. In the analyses, various phenomena, such as re-melting of the weld metal by a new welding, redistribution of the welding stresses by re-melting, change of metal properties due to thermal cycles, such as phase transformation were taken into account. The theoretical analysis of stress relief annealing was also performed. Experiments were conducted on two models, which were prepared by cutting out from a long welded joint, and each model was used to measure the residual stress of welding and the residual stress of stress relief annealing. Both results of the theoretical analyses and experiments indicated good correspondence. It turned out that no special attention needs to be paid to the accumulation of residual stress in the central part of the plate thickness in respect to weld cracking, since the maximum residual stress occurs near the top or bottom surface. This study suggested that intermediate annealing of welded structures was not necessary solely for relieving residual stress generated inside the plate thickness [10]. This new finding had greatly helped reduce the cost of manufacturing large welded structures.

So far, using the new analysis method, the basic analysis procedures for the problems of moving heat source, local stress-strain distribution for cracking, and problems of multilayer welding were developed. Since then, a series of theoretical analyzes were performed on various types of welded joint and about 200 papers were published, intending to establish the framework of Computational Welding Mechanics [11].

3.2 Improvement of analysis accuracy and convergence of solution in 3-D problems

During welding the temperature distribution of the joint changes every moment and the mechanical behavior changes from elastic to plastic and material properties change rapidly with temperature changes. These abrupt changes influence the analysis accuracy and convergence of the solution. An incremental method is employed to analyze such a problem that changes with time. One measure to this problem is to adopt short time increments, but this method alone is not enough, and careful treatment must be taken against various abrupt changes. For the transition stage from elastic to plastic, weight factor was introduced. For the sharp change of the material properties, smoothing of its change was adopted [12-13]. In addition, it was devised how to determine the temperature increment and how to determine the size of the finite element [14]. This improved method applied successfully to 3-D residual stress and deformation analyses for the assembly process of a compressor by shrinkage fit and plug welding and also pipe-plate joint with holes by multi-pass welding with Wang [15].

3.3 Measurement of residual stresses using inherent strains as parameters

In order to accept the valuable information obtained from the analysis as to be rational, the result should be validated by experiments, specifically three-dimensional residual stress in multilayer welding of thick plates. For this purpose, new methods for measurement of three dimensional residual stresses should have to be developed, because no such experimental method was available except one by Rosenthal with Norton [16]. The method in the paper is basically a stress relief method by cutting. The first step in this process is to cut a specimen in a 3-D stress state into a 2D stress state and measure the two-dimensional residual stresses. The stress released in this first process is measured only at the upper and bottom surfaces of the original thick object, and the internal distribution of stresses is estimated from these measured ones. As this estimation is arbitrary, it was assumed as linear in this method. It was proven inaccurate according to the numerical experiment by the FE analysis [17].

Ueda paid attention to the relation between residual stress and its source that is named the inherent strain [18]. It was pointed out that the welding residual strain and deformation generated in a joint is composed of the sum of elastic strain and inherent strain (plastic strain in this case) and the following two important facts exist between them;

1. The inherent strain distribution in a body does not change, if it is cut without producing new plastic strain, since the inherent strain is irreversible. However, the residual stress distribution may change due to stress-relief by the cut.

2. If the distribution of inherent strain is known, the residual stress can be computed by elastic analysis. This inverse analysis is also valid, if the condition of zero strain is properly introduced.

Based on these facts, Ueda developed a basic theory of measurement of residual stresses by sectioning method with Fukuda [19]. When the original body is cut into small pieces in 2-D stress state, the residual stresses may change but the inherent strains in the pieces do not change. From the small pieces cut even inside of the body, inherent strains can be evaluated by the inverse elastic analysis from the residual stresses reminded in the pieces. Once inherent strains in the pieces are estimated and the entire distribution can be obtained by reassembling them. With this distribution, the entire distribution of residual stress can be computed by the elastic calculation [20]. This method is believed to be the first and the most accurate theoretical method for measurement of 3-D residual stresses. At the1981 IIW Assembly, Professor Ueda presented a paper on measurement of welding residual stresses in thick plate joint with multi-layer welds [21]. Before the presentation, Professor Soete, President of IIW, requested him to deliver his paper so that everyone could understand it because the paper was very innovative.

The residual stress in fillet welds has significant effect on its fatigue strength. The residual stress varies within very small regions of the welds and it is very difficult to measure directly. With the aid of the inherent strain, a measuring method was developed. First, its inherent strain distribution was assumed to be expressed by parametric functions with a small number of coefficients. The coefficients can be determined by a small number of measurement of residual stresses on the surface and the overall residual stresses induced in the weld can be computed by the elastic analysis [22]. Using this method, the actual residual stresses in the bead-on-plate with Ma [23] and furthermore those in the fillet weld of a T joint were measured successfully [24, 25]. Further, a measuring method of residual stresses induced in explosively clad plates was also developed with Murakawa [26]. Society of Experimental Mechanics and American Society for Metals, International, invited Prof. Ueda to write a new and innovative residual stress measuring method for publishing a handbook and a monograph, respectively [27, 28].

3.4 Prediction of welding residual stresses

It may be beneficial if the residual stress and deformation of the structure due to welding can be predicted at the design stage. For that purpose, thermal-elastic-plastic analysis by the FEM can be performed. However, when the structure becomes large, the time and labor required for the calculation become enormous. One way to solve this problem is to idealize the generating process of residual stress and deformation and focus on the consequence, which is the inherent strain.

A practical and simple predicting method was proposed using the inherent strain [29]. When a butt welded joint of plates is sufficiently long as seen in actual structures, the inherent strain distribution is trapezoidal and uniform along the weld line except near both ends. Imposing the inherent strain to the plate, residual stress can be completely reproduced by elastic analysis. This method was successfully applied to not only butt welded joints but also built-up T- and I- welded joints with Yuan [30]. In order to use this efficient estimation method of residual stress, it is recommended to create a database of inherent strains. To support this purpose, a simple method for estimating inherent strains suitable for various welding conditions was proposed [31] with Lou and showed that the method can be applied to predict not only residual stress but also welding deformation in such cases as butt joint of plates with multi-pass beads, and those manufactured by narrow gap welding [32, 33] with Murakawa.

3.5 Plate bending by line-heating

In the construction stage of ship structures, many curved plates are manufactured. This work is mostly dependent upon the skill of well-trained craftsmen by line heating using gas-line-heating (or induction heating) and water-spray. To solve the problems associated with today’s decrease of such craftsmen and the demand for high efficiency, one of the measures is to promote mechanization of the procedure. In order to fulfill that purpose, it is first necessary to theoretically elucidate the process of plate bending and to embody the machining process based on that theory.

It can be manufactured by performing bending and shrinking processes to make a curve plate from flat plate. These processes are operations to cause plastic strains. This process is similar to the production of welding residual stress and deformation, which are produced by plastic strains i.e. inherent strains. As described in the previous section 3.4, the source of residual stress is plastic strain, which can be obtained inversely from the residual stress measurement based on the inherent strain theory.

In this task, the plastic strain required for this manufacturing process is obtained as follows. With the aid of the FEM, an elastic-plastic analysis is performed to the process of pushing a planned curved plate onto a flat plate and consequently, the elastic-plastic strain distribution is obtained. The plastic strain distribution obtained by this calculation is the source to generate the curved shape. Next, the relationship between the line- heating conditions and the resulting plastic strain distribution is derived by theoretical analysis or/and experiments. This research project was conducted as a joint project between Prof. Ueda’s research division and a shipyard from1991. This was the first case where the know-how of the craftsman is clarified by the theory and realizing mechanization of the process with Murakawa [34-36]. Prof. Ueda and collaborators received two awards for its striking originality from the SNAJ [Award 9] in 1999 and from the JSPMI [Award 11] in 2001. Currently, an automatic line-heating machine for plate bending has been developed and marketed.

3.6 Numerical simulation of deformations caused by cutting and welding for ship assembling with high precision

(1) Cutting

To realize automation and mechanization in shipbuilding industry it is necessary to maintain high precision in all the assembly processes, such as cutting, bending and welding. To this end, a joint study with a shipbuilding company was started. The study started with the cutting process, which is the first stage of the entire process, was very important. Any error introduced in the first stage propagates to the following stages and it may result in a big error which is beyond the tolerable limit of automated machines. Numerical simulation of the deformation of a plate accompanying the cutting of the plate was performed by the FEM. Comparing the computed results with the experimental transverse deformation and the residual stress distribution, it was found to be in very good agreement [37].

The cutting error (deviation from the originally specified cutting line) was caused by the following three reasons:（1）Mechanical factor, （2）Thermal deformation during cutting, and (3) Inherent residual stress originally generated in the plates. Large error was observed in the case of one-side cutting in contrast with parallel one.

(2) Welding

Following the cutting process, it is necessary to predict welding deformation in advance and clarify the influence of various factors in order to promote automation and mechanization. As the first step, the in-plane transverse deformation of one-sided automatic welding was studied using the FE analysis. The effects of various factors, such as the type of tabs, the pitch of tack welds, the magnitude of root gap, the distributions of local heating and initial stresses, and the welding sequence were investigated [38].

The computed transverse deformations showed good correspondence with the measurements for cases with different types of tabs and several pitches of tack welds. It was found that the effect of changes in the tabs and tack welds on the deformation was only 0.1 mm. In general, widely distributed stress, such as the thermal stress produced by local heating had relatively large effect.

These initial gaps were closed by tack welds before FCB welding to maintain the good quality of the weld. However, this correction of the gap produced initial stress in the plate and it influenced the welding deformation. It was seen that the initial gap should be kept smaller to reduce the welding deformation [39].

In succession, numerical simulation of out-of-plane deformation caused by FCB butt welding on large size steel plates was conducted using 3-D FE analysis method that was developed for this study [40, 41] with Gu. The simulation results revealed the role of the main influencing factors. （1）The gravity of the plate had large influence on the deformation.（2）A working bed was better to be densely arranged grid or flat surface. （3） The shape of angular distortion was affected by factors such as constraint conditions, backing force and initial deformation, and (4） Forced constraint was an effective measure to control angular distortion.

3.7 Weld cracking and prevention

(1) Oblique Y-groove weld cracking test specimen

In order to prevent the weld cracking, the oblique Y-groove weld cracking test specimen has been widely used as a standard cold cracking sensitivity test specimen to select appropriate materials and welding conditions including preheating temperature. The size of the specimen is B=150, L=200, h=thickness, and the slit length: ℓ=80, (in mm). The critical plate thickness, h_{cr} is defined as $h_{cr} = q/c\rho(Tm - T_i)^{1/2}$ (in mm), where T_m=700°C, T_i =15°C, ρ=7.66g/cm^3, c=0.188cal/g・°C, ξ= 0.75.

It may be simply stated from the mechanical aspect that the cold crack initiates when the stress and strain induced at a point reach the critical values.

A series of thermal elastic-plastic analysis was performed on plates with different in size and slit length and it was found that there are three kinds of deformation which cause thermal stress and strain: (1) the shrinkage of the weld metal, (2) locally confined thermal deformation of the base plate and (3) over-all deformation of the base plate. In case of short slit, the over-all deformation was the main cause of thermal stress. In case of long slit, (1) and (2) were the main causes and then the conventional concept of restraint intensity was applicable to estimate the residual stress [42].

Subsequently, the restraint stress and strain produced in the commonly used test specimen were evaluated in the case of different in size and thickness. Their magnitudes vary with the amount of relative critical plate thickness ratio ℓ/h_{cr}. Judging the severity of the mechanical condition of the specimen from the magnitude of restraint stresses and strains, the infinite plate is the severest. The infinite plate may be replaced by a finite plate of which size ratio is $B/\ell \geqq 4.0$, $L/\ell \geqq 3.7$. When the thickness of the test specimen increases, the mechanical conditions become more severe. However, as the plate thickness approaches h=50 mm, the severity of mechanical conditions almost saturates in case of mild steel. From this fact, it can be seen that the plate thickness of 50 mm is sufficient to select the welding conditions for thick plate of mild steel.

In the case of a specimen of the standard size, of which size ratio of B/ℓ= 150/80=1.875 and L/ℓ= 200/80=2.5, the stress-strain generated in weld metal becomes approximately maximum under Q = 17,000 J/cm and ℓ/h_{cr} being between 2.5 and 3.5. Consequently, it was found that the standard specimen exhibits the maximum mechanical restraint condition when ℓ/h_{cr} is between 2.5 and 3.5.

In the study, the relation between the plastic restraint strain and the restraint intensity were discussed in details [43].

A series of theoretical analyzes was conducted on the restraint stress・strain (residual stress・strain) generated in the weld metal of the oblique Y-groove weld crack test specimen by changing the steel type, heat input, preheating temperature and base plate thickness. The result indicated that the distribution and magnitude of restraint stress and strain along the slit varied according to changes in the welding conditions. In contrast with this, the restraint intensity (degree of elastic response against the shrinkage of weld metal) of the specimen is evaluated automatically from the geometrical sizes. Therefore, the restraint strain (=sum of elastic and plastic strains) should be a better index of mechanical condition than the restraint intensity, since the restraint strain faithfully reflects the differences in various conditions.

In the cold cracking parameters (P_w and P_{HA}), the restraint intensity is adopted as the index of mechanical condition. To check the effectiveness of these indexes, the data of approximately 500 cracking tests was re-analyzed adopting the restraint strain. It was found that the newly proposed index more faithfully reflects the influence of different welding conditions. The calculation of this index requires complicated computation, but in order to put this index to practical use, a formula for easily estimating the critical constraint strain for three types of high-strength steel was derived. Based on the cold cracking parameters (P_w and P_{HA}), which were modified with this critical restraint strain, a new selecting method of the critical preheating temperature T^* was developed, and simple and accurate expressions for T^* were derived [44, 45] with Kim.

(2) Multi-pass welded corner joints

Multi-pass welded corner joints are often used in bridges, industrial machines, etc. At these joints, in addition to root cracking, “opening type” lamellar tearing, i.e. tearing which reaches to the surface is occasionally observed at a position outside the heat affected zone (HAZ). This type of tearing shows a stepped fracture composed of terrace and wall fracture, typifying lamellar tearing. For this research, the corner joint weld cracking test (CJC test) apparatus was developed and conducted a series of experiment to find the critical bending restraint intensity. Using this apparatus, the mechanism of opening type lamellar tearing and root cracking in multi-pass welded corner joints and prevention methods were investigated by theoretical analysis using the finite element method and experiments [46] with Chiba.

The main results were as follows: （1） Opening type lamellar tearing occurs when the intensity of bending restraint is large and root cracking occurs when it is small. The occurrence of such cracks is closely related to the distribution profile of welding residual stress. （2）Diffusible hydrogen has little influence on initiation of these weld cracks. This implies that welding residual stress and strain are the main causes. (3) To prevent lamellar tearing, the following measures are effective: to use steel plates of good ductility in thickness direction; to reduce the throat depth; to change the shape of the preparation and to use submerged arc rather than manual metal arc welding. To prevent root cracking: to reduce throat depth; and to use submerged arc rather than manual metal arc welding. (4) As it was recognized that the corner joint weld cracking test (the CJC test) simulated well the mechanical behavior of joints by welding in actual structures, such welding conditions that do not cause the welding cracks can be selected based on the critical intensity of bending restraint for lamellar tearing (K^l_{Bcr}) and the critical intensity of bending restraint for root cracking (K^r_{Bcr}) that were obtained from the CJC test conducted for the specified materials and the welding conditions.

(3) Prevention of stress corrosion cracking of pipe joints

Many stainless steel pipes such as SUS 304 are used in various plants including nuclear reactors because they have excellent corrosion-resistance, strength at high temperature, and fracture toughness at low temperature. Nevertheless, intergranular stress corrosion cracking may occur in some specific conditions on the inner surface of the welded joints of stainless steel pipes since the conventional welding produces tensile residual stress on the inner surface.

One way to prevent this cracking is to use the heat sink method, which converts the tensile stress on the inner surface of the pipe into compressive stress. In this method, water is sprayed on the inner surface to cool it compulsorily while welding the pipe joint. The mechanism of production of residual stresses by this method was clarified by both theoretical analyses and experiments. The conditions under which this method could be used optimally were shown for different size of pipe [47] with Shimizu.

3.8 Characteristics of brittle fracture under general combined modes

Very rare in the 1970s, a large bi-directional loading device of 300 tons vertically and 150 tons horizontally was installed at Osaka University. Prof. Ueda started a joint research on brittle fracture of steel using this device with Ikeda of a steel maker. Firstly, a series of experiments on cruciform steel plate specimens with an inclined crack at the center was conducted applying uniaxial and bi-axial tensile loads [48]. Then, another series of experiments were carried out on PMMA (polymethylmethacrylate) specimens which fractures in a perfectly brittle manner. Cracks in the specimen were machined being inclined to the horizontal line as well as the plate surface, simulating failure in the general combined Modes of I, II and III. In addition, elastic and elastic-plastic stress analyses of the specimens were also performed [49]. The results of researches on brittle fracture can be summarized as follows [50, 51].

Firstly, on the basis of test results on PMMA specimens, measured fracture strength under general combined modes were compared with those predicted by the fracture criteria expressed in terms of: (1) maximum tangential stress, $[\square_{\square\square}]_{max}$ □□□□□□□maximum energy release rate at the propagation of a small kinked crack, $[G^k(\square)]_{max}$, and (3) newly derived maximum energy release rate at the initiation of a small kinked crack, $[G^k(\square)]_{max}$. It was found that the $[G^k(\square)]_{max}$ or $[G(\square)]_{max}$ criterion was very effective to predict both the direction of initial crack propagation and the fracture strength. These energy release rates are expressed in closed forms, and the interaction curves of the brittle fracture strength were derived under arbitral combined Modes I, II and III.

Secondly, for brittle fracture accompanied by yielding, the followings were found on the basis of test results on mild steel specimens tested under bi-axial tensile loads at various low temperature together with the results obtained by FEM elastoplastic stress analyses. In case of brittle fracture accompanied by small scale yielding, the $[G(\square)]_{max}$ criterion predicts well the direction of initial crack propagation but estimates lower fracture strength than the measured strength. In case of brittle fracture with large scale yielding and/or general yielding, the direction of initial crack propagation was nearly normal to the resultant vector of COD (crack opening displacement) in the opening and sliding modes at the crack tip. In this case, the modified COD criterion predicts well the direction of initial crack propagation but lower fracture strength.

3.9 Two research subjects continued by successors

After retiring from Osaka University in 1996, Professor Ueda reduced his research activities. His colleagues voluntarily took over the research and continued to develop computational welding mechanics. Here, two research themes that Professor Murakawa, his successor, continued will be introduced; (1) Prediction of welding distortion with Liang et al. and (2) Reduction of computing time with Nishikawa et al.

(1) Prediction of welding distortion

To control welding distortion is an important issue in the construction stage in order to maintain good quality of products and good appearance. For this purpose, a prediction method was developed based on the concept of inherent deformation in similar to that for residual stress [52]. Although the inherent deformation is an integration of inherent strains, collection of data on inherent deformation by experiments requires sophisticated method. Comparison of welding distortion of stiffened plate predicted by the inherent deformation and test results indicated good correspondence and the proposed method was proven a useful tool [53].

(2) Reduction of computing time

To predict welding residual stresses and distortion produced in structures with complex geometry, three dimensional thermal elastic-plastic FE analysis is performed. Generally it requires very long computational time. This problem was overcome by Iterative Substructure Method (ISM). This method was based on the idea that the region in strong nonlinearity is limited in a very small region with high temperature which moves with welding torch and remaining large region behaves almost linearly. By focusing computational effort to small nonlinear region, great reduction of computational time was achieved [54].

3.10 Summary - Computational Welding Mechanics.

Thermal elastic-plastic analysis of welds started with Professor Ueda with Yamakawa. The basic theories of analysis and measurement of welding residual stress were developed by Ueda with

Fukuda. In parallel with this, new possibilities of the inherent strain method was explored and its applicability to the measurement of residual stress in three dimensions and the prediction of residual stress and deformation was expanded. This analysis method was applied to analyze the residual stresses of various types of welded joints and the producing mechanism of welding residual stresses was elucidated one after another. Furthermore, mechanization of the plate bending process of steel plates that relied on the skills of skilled workers was successfully achieved by Ueda with Murakawa. As the next stage of research, those proposed basic methods were further expanded toward practical application for analysis, measurement and prediction of welding residual stress and deformation. In this way, Prof. Ueda established a framework of the computational welding mechanics and it has become an indispensable tool [Award 5] in1993.

In 1993, Prof. Ueda retired from Osaka University and had been engaged in research in this field for 35 years as a frontrunner and presented about 200 papers. As a summary of his research work, he published a monograph entitled “Computational Welding Mechanics” composed of selected papers among these written in English in commemoration of his retirement [55]. For his pioneering and outstanding achievements in the field of computational welding mechanics, he received the Academic Contribution Award from the Japan Welding Society [Award 6] in 1995, and later the IIW Arata Award for his outstanding achievement in fundamental research [Award 10] in 2000 (IIW: International Institute of Welding).

In connection with this, Dr. Radaj, Senior Research Manager at Daimler-Chrysler in Stuttgart, researched 838 documents in the field of welding mechanics and published a book “Welding residual stresses and distortion, Calculation and measurement,” from DVS-Verlag in 2003 [56] and depicts on its inside front page that “Dedicated to Yukio Ueda and John Goldak, Pioneers of Computational Welding Mechanics”. To further develop the achievements of these two pioneers, the Pioneers Award was set up within the International Conference of Welding Science and Engineering (WSE), which has been held every two years from 2005. The first award was given at the 4th conference of the WES, which was held at JWRI, Osaka University in 2011.

He participated in academic activities in addition to his research activities. From 1988, he was elected to the Board of Directors of the Japan Welding Society (JWS) twice and later he became a special member of the Society in 1998. He had been an active expert at the International Institute of Welding (IIW) for many years. He was the secretary of a committee (later Study Group RES) to exchange information on welding research activities worldwide from 1981 to 1991. He also served as a member of the Technical Committee, an advisory body on technical issues handled by IIW from 1991 to 1999.

In 1979, He was invited by Xi’an Jiao Tong University soon after China started reform and opening. He lectured “Computational Welding Mechanics” to researchers selected from all over China for two months in English. This opportunity must have been the first to introduce computational welding mechanics to China. Since then, academic exchange between Welding Research Institute of Osaka University and Chinese universities has greatly advanced. In 1980 and 1987, he became Adjunct Professor of Xi'an and Shanghai Jiao Tong Universities, China.

Ueda and Murakawa (Osaka University) were invited to International Graduate Research School to deliver a series of lecture on Computational Welding Mechanics, which was organized by Prof. Jensen at DCAMM of Denmark University of Technology in 1998.

Prof. Ueda gave lectures on Computational Welding Mechanics at various universities, research institutes, academic societies or international conferences at the request.

Professor Ueda and his collaborators made their own in-house computer program, JWRIAN, to proceed with the research. This computer program was enhanced every time they solved a new problem. On the other hand, several well-known commercial programs were on the market. Using these programs many engineers conduct welding residual stress and deformation analysis as a routine work. When they use the programs, they must idealize the heat source, material constants, etc. with reasonable accuracy and need to fully understand the meaning of mechanical phenomena represented by analysis results. In order to perform these works, engineers with little experience in welding engineering must acquire the basic knowledge necessary. For this purpose, a Japanese book was published, being accompanied by an educational computer program and its manual in 2007. Chinese version of this book was on the market in 2008 and in 2012 also English version; Welding deformation and residual stress prevention was published from Elsevier, BH [57] (Ueda, Murakawa and Ma, 2012).

Presently, the computational welding mechanics is an indispensable tool and widely used. However, when the method is applied to more practical problems, there are still many problems to solve since the problem is of multi-disciplinary among heat source, materials and mechanics. One of the problems is how to obtain accurate information about material properties that are influenced by thermal cycles, mechanical treatment, etc. The other is how to reduce the accumulation of calculation errors because this analysis requires a lot of iterative calculations.

4 Research Life on Computational Structural Mechanics for Ultimate Strength Analysis: ISUM (Idealized Structural Unit Method)

In order to analyze the entire process of mechanical behavior of structures to the ultimate strength, considering local failures of the structure, the FEM is obviously a most powerful tool, since detail analyses of behavior of elastic-plastic large deflection of structural members are possible. However, it would take a lot of computation time, since local failures are composed of two kinds of non-linearity, which are the material non-linearity such as yielding and the geometrical non-linearity such as local buckling and post-buckling.

Under the computer environment around 1970, many new analysis methods had to be developed in order to proceed with research on the ultimate strength analysis.

4.1 Buckling and plastic collapsing strength of rectangular plate and stiffened plates

He started the finite element analysis with a study on local failures. His first paper was on elastic-plastic buckling of a plate with welding residual stresses. Developing the computer programs to deal with buckling, post-buckling, elastic-plastic large deflection etc., analyses on the collapsing strength of structural components, such as plates, stiffened plates, girders etc. were extensively conducted taking account of welding residual stresses and deformation.

His research interest was on the ultimate strength of the ship in service conditions. The main structure of the hull is a kind of so-called box girder. It is one of the typical structural types of welded structures. In these structures, the deck plates on upper and bottom are the main strength members, which are usually subjected to compressive and/or tensile loads. The deck plates are reinforced by a number of stiffeners, and are subdivided into narrow strip plate elements. When the ultimate strength of the deck is evaluated, those of strip plate elements and stiffened plates play important roles. These structural elements are always accompanied by welding residual stresses and distortion. From these viewpoints, an extensive investigation was proceeded on the ultimate strengths of a rectangular plate and a stiffened plate under thrust taking into account of welding imperfections with Yao.

Firstly, measurement of the welding deflections on 33 deck panels of a bulk carrier and a pure car carrier was conducted, and the deflections were represented by a series of functions with coefficients for each component. With the data, an idealized simple deflection model was proposed [58].

In the research, considering the continuity of a panel in the stiffened plate, a rectangular plate panel was regarded as being simply supported and maintained straight after deformation along the edges. Theoretical analyses by both analytical method and the finite element method, and experimental study were performed. The research started with square plates [59] and subsequently was followed by rectangular plates. From the results of this study, the following findings were obtained regarding the behavioral characteristics of long rectangular plates [60].

In case of thin plate, only one component mode of the initial deflection is amplified and becomes stable above the buckling load. This component mode is not necessarily the buckling mode and usually one or two modes higher. This component deflection is usually pretty smaller than the maximum initial one.

In case of thick plate, a certain portion of the plate, where the largest curvature of the initial deflection is located, is decisive to spreading of yielded region, which leads to collapse.

Concerning plate of medium thickness, the mode of the initial deflection may change as the deflection increases. In this process, spreading of yielded region may be accelerated or decelerated by interaction among the component modes. This phenomena makes lower or higher the ultimate strength.

Both welding residual stresses and initial deflection reduce the compressive buckling and ultimate strengths of plates. The reduction in ultimate strength is maximum when $(b/t)\sqrt{\sigma_Y/E}$ is about 1.8 [61].

When the stiffener is symmetric with respect to the middle plane of the plate, there exist three typical collapse modes of stiffened plates according to the stiffness ratio of the stiffener to the plate, which are: (a) Mode OO (overall collapse after overall buckling); (b) Mode LO (overall collapse after local buckling) and (c) Mode LL (local collapse after local buckling). The minimum stiffness ratio of stiffener for collapse was newly defined in similar manner to that for buckling.

For the one-sided stiffened plate, the minimum stiffness ratio against the ultimate strength can also be determined as the stiffness ratio evaluated at the intersecting point of the overall buckling strength curve and the ultimate strength curve for Mode LL (local collapse after local buckling) in similar way for both-sided stiffened plates. However, about 3.5 times the stiffness ratio that defined above is necessary to attain the possible maximum value of ultimate strength.

Both initial deflection and welding residual stresses reduce the capability of the minimum stiffness ratios for buckling and that for collapse, and consequently the possible maximum value of buckling and ultimate strengths, which are guaranteed by these minimum stiffness ratios [62-64].

Based on the results of previous research, an accurate and simplified method for estimating the ultimate strength of a long rectangular plate panel in a stiffened plate was proposed [65]. The procedure of estimation consists of three steps: (1) welding residual stress (2) welding deformation and (3) compressive ultimate strength with consideration of the effects of (1) and (2). The first two were estimated consistently in terms of inherent strains and deformation, which were diverted from the research results of welding mechanics. The equivalent plate defined in [58] was used in (3) to derive several ultimate strength estimation equations.

The corner bracket, which is usually provided at the joint between the deck beam and the side frame of the hull, reduces stress concentration and smoothes the flow of force. A method of determining the optimum thickness was proposed with Yao. Such a bracket should have sufficient strength so that a bracket does not undergo buckling and/or plastic collapse until the beam with this bracket collapses under extreme loads. At the same time, it should be noticed that a bracket is a secondary strength member, and it is of no need for a bracket to carry further loads after the main strength member has reached its maximum strength and lost its function. Therefore, it may be said that the necessary and sufficient conditions for a bracket are to have such thickness so that its buckling and/or plastic collapse occurs simultaneously when a deck beam attains its ultimate strength. This is the basic idea of the proposed method to determine the optimum thickness of a corner bracket [66].

4.2 Basic concept of ISUM

From these analyses, Ueda noticed that it requires enormous computing time and manpower to carry out ultimate strength analysis of an entire structure by the FEM. He tried the finite strip method [67] and the incremental Galerkin method [68], but could not reduce the calculation time. Therefore, a great concern was how to reduce computing time maintaining reasonable accuracy.

In order to make the computing time shorter, progress in the following three fields are essential:

1. Far advanced hardware: high speed computation,

2. Very smart mathematical treatment and algorithms: efficient calculation,

3. Development of intelligent physical models: idealization of non-linear behaviors of structural components to be expressed in simpler way:

He considered that it was possible to realize any progress in the last category through structural engineering.

In the early 1970s, Prof. Ueda proposed the concept that an intelligent physical model should have the following three important properties. Therefore, this is the essential characteristic of the Idealized Structural Unit Method, ISUM. Based on this basic concept, the first structural unit; Deep Girder element, [69, 70] and several other ones, that are named ISUM elements, were developed together with a graduate student, Rashed. The three important properties are as follows:

1. Large size elements with fewest degrees of freedom:

Firstly, component members of structures should be classified into limited number of simple configurations such as beams, columns, and plates. The loads acting on these individual members are not entirely arbitrary but rather specified according to their functions. These structural components are dealt with as units (elements) for analysis. Each unit has nodes at the ends of beams, columns, etc. and at the corners of plates, and solid blocks. Limited numbers of degrees of freedom (displacement components) are specified only at each node. No degrees of freedom are allowed inside these units. Consequently, the degrees of freedom of the whole structure are greatly reduced in comparison with the direct application of the FEM. This treatment makes the analysis simpler and much more efficient.

2. Material non-linearity: that is plasticity.

Under increasing loads, yielding initiates in parts of structural members, and the yielded zones gradually expand. The effect of these zones may be idealized and treated at each node in such a way as the generalized plastic hinge. Later, this plastic hinge method will evolve into the plastic node method.

3. Geometrical non-linearity: that is buckling, post-buckling, and/or large deflection.

Buckling of the member under in-plane or axial forces may occur, and thereafter in-plane or axial stiffness of the member decreases. This causes a redistribution of forces and influences the post-buckling behavior of the member and structure. One method to treat such complex behaviors in simple manner is to construct a buckling interaction relationship and express the post-buckling stiffness in terms of the effective width. Advanced treatment developed later is to define simple and accurate deflection functions for post-buckling behaviors of the respective members.

4.3 Idealization of Material non-linearity: Plastic Node Method

In order to realize the concept of the analysis method of the ISUM, Ueda intended to more generalize the concept of the plastic hinge method as a method of idealizing the nonlinearity of materials so that it could be applied to ISUM elements of large size such as plates, stiffened plates, etc.

At Lehigh University around 1960, he learned a new concept of limit design of steel frame structures introducing simple plastic hinges. When a frame structure is subjected to increasing loadings, plastic zone in the structural components spreads from highly stressed zone. In the plastic hinge method, the plastic zone spreads over the entire cross section, which is considered as a plastic hinge. This is a kind of idealization to analyze elastic-plastic behaviors of structural components.

In the classical plastic hinge method, introducing plastic hinges, several final collapse modes of a frame structure are assumed, to which the mechanism method is applied to find the collapse load. The process to the final collapsing state was ignored and calculations was performed for the assumed trial collapse modes. It became very difficult to predict possible collapse modes that could occur in complex structures.

Applying the incremental procedure, Ueda had improved the simple plastic hinge method so as to analyze the elastic-plastic behavior of structures under increasing loads [4] in 1969. With this improved plastic hinge method, new plastic hinges can be detected step by step, and satisfying the plastic interaction relationship at each plastic hinge for each load increment and finally the collapsing state can be found directly. In the analysis, the elastic-plastic stiffness matrix can be derived in explicit mathematical forms. As no numerical integration for the stiffness matrix is required, the computing time significantly is saved.

Furthermore, this advanced plastic hinge method was tried to apply to plates and solid blocks, which are subdivided by finite elements. However, there existed a fundamental difficulty to apply the method to plate bending, since the concept of section forces and moments defined at the plastic hinges of frame structures could not be applied directly to plate elements. One of the main reasons was that assumed plastic hinge lines along the boundaries or inside of the element cannot be defined, since the internal forces and moments are not uniform along the hinge lines and change at each step of load increments. Another important fact was that the full plastic condition of the elements gathered at a node may not be satisfied at the same time. This implies that elastic elements and plastic elements co-exist at the node.

Keeping these problems in his mind for 10 years, he finally recognized a very important fact that effects of plastic zone prevailed inside of the elements are taken into account in the nodal forces that is evaluated by integration of stresses in the element. The nodal displacements of an element are derived as the counter part of the nodal forces without forming plastic hinges. Accordingly, the nodal displacements include the effect of plasticity in the element. He accepted such fact that each element joining at a node satisfies the plasticity condition separately at different steps of the loading condition. Then, the elastic-plastic stiffness matrix of each element can be derived by the standard procedure, which automatically takes into account of the reduction of stiffness of the elements due to plasticity. Based on this theoretical background, Ueda developed“Plastic Node Method（PNM）” that can be applicable to any structural elements including plates and solid blocks [71] together with Yao and Fujikubo, in 1981. He generalized the theory further with Fujikubo in 1991: When the method is applied to the specific elements, the mechanism of plastic hinges, plastic hinge lines, and slip lines can be easily be generated to the element boundaries. This indicates that this generalized method is a comprehensive method of plastic analysis applicable to one- to three-dimensional finite elements, including the plastic hinge method, the plastic hinge line method, etc. [72].

It had been a challenge to consider strain-hardening effects in the framework of Plastic Node Method where the plastic deformation is not treated as plastic strains but just as nodal displacements. A concept of equivalent plastic work was introduced, in which the strain-hardening effect within a finite element was concentrated at the nodal points by equating the plastic work at the plastic node to that in the plastic region spreading in the element. Applying this concept, a nodal-point strain-hardening rate was derived and the generalized elastic-plastic stiffness matrix was formulated [73] with Fujikubo. This method was further extended to deal with large deflection and cyclic hardening effects and applied to the collapse analysis of offshore frame structure that is for elastic-plastic large deflection analysis under dynamic cyclic loadings [74] with Bai.

4.4 Idealization of geometrical non-linearity: ISUM Elements

Marine structures may be classified into two types: frame structures, and plate ones. Both types of structures exhibit local failures, such as local yielding, local buckling, etc. before attaining the ultimate strength.

The plastic node method was developed for an idealization of material nonlinearity. Next, an ISUM element with idealized geometrical nonlinearity is necessary. According to chronological order, the first ISUM element was a deep girder element (DG element), and a tubular pipe element (TP element) was the second. Plate and stiffened plate elements were subsequently developed. Furthermore, various useful ISUM elements necessary for the research task were developed. The structure to be analyzed was assembled with these ISUM elements, and procedure of the analysis method was completely similar to the conventional FEM. The analysis method was extended to take into account of large deformation effects in the overall behavior of the structure, and the examples were analyzed [75].

(1) Deep girder element (DG element)

In a trend of rapid increase of the size of tankers in 1970’s, it was an urgent matter to assure the strength of thin deep webs of transverse rings and girders that sustain large shearing forces, which may cause web buckling.

In order to perform the desired analysis, an ISUM deep girder element (DG element) was developed. It was a part of a deep girder between two adjacent vertical stiffeners attached to the girder web. The performance of the element was ascertained in comparison with the results of experiment on several girders of unequal flanges [69, 70] with Rashed. Using this DG element, transverse strength of transverse ring models of tankers was analyzed and compared with model experiments in [76]. In general, good correlations between them were observed to verify the usefulness of the DG element. The paper [69] was given the best paper award from the Society of Naval Architects, Japan for its innovative analysis method in 1974 [Award 2].

The function of this DG element was developed so as to deal with local buckling, post-buckling, and yielding of web, and local yielding of flanges, and fully plastic condition through the cross-section of the girder. This element has only two nodal points, which are designated at each end cross-section and at mid-height of the web, where three nodal forces: axial force, shearing force and bending moment and corresponding nodal displacements are considered. This ISUM element has only 6 degrees of freedom.

Web buckling of DG elements is detected by the buckling interaction relationships derived beforehand. Post-buckling stiffness is evaluated through the concept of effective width. The ultimate strength interaction relationship under various mechanical phenomena and the fully plastic relationship in the absence of buckling were established. The derivation of this element required complex and intelligent work. This was the reason why only a few engineers could understand it. Further, a product oil carrier was designed by a new design concept, so that it consisted of full double bottom and unidirectional girder systems. In order to check its safety, a portion of the hull between two transverse bulkheads was modeled and analyzed with DG elements and newly developed rectangular plate elements (RP element) [77].

(2) Tubular pipe element (TP element) and joint element

The tubular pipe element (TB element) was formulated with good approximate deflection functions to cope with buckling and post-buckling of the element. Using this element, the ultimate strength analyses of frame structures were successfully performed with the help of the plastic node method [77, 78] with Rashed. One of examples of the analyses was a jacket structure. As the strength of tubular joints of the structure is influential to the overall strength, ISUM tubular joint elements were also developed to improve the analysis accuracy [79].

As jackets are often subjected to minor collision by supply boats, some tubular members should be damaged. The effect of damage was taken into account to develop a damaged tubular pipe element [80] with Rashed.

(3) Rectangular plate element (RP element)

The ultimate goal of development of the ISUM analysis method is to analyze the ultimate strength of entire ship hull structures. To this end, at the first step, one plate panel (a plate bounded by four stiffeners) of a stiffened panel is regarded as one structural unit according to the basic concept of

ISUM. An ISUM rectangular plate element capable of handling buckling, post-buckling stiffness and ultimate strength of individual plate panels within a limited computing time has been developed.

This element takes into account two types of non-linearity: material non-linearity (such as plasticity) and geometrical non-linearity (such as buckling). For the first non-linearity, the plastic node method is applicable. For the second non-linearity, it required three stages of progress to handle geometrical nonlinearity. The element in each of these stages are called that of the 1st, 2nd, and 3rd generation respectively.

At first, the ISUM rectangular plate element of the 1st generation was developed [81, 82] with Rashed and Paik.

Considering the continuity of plate panels in a stiffened panel, and the presence of stiffeners at the four edges of each plate panel, a rectangular plate element is assumed to be simply supported along the four edges, which are kept straight during deformation. The element is also assumed to be subjected to in-plane longitudinal and transverse forces, in-plane shearing force, and in-plane bending moment. The behavior of this element is expressed by the relation between the nodal forces and nodal displacements designated at each of the four corners of the element. The relation is expressed in an incremental form. The element is treated as a membrane, that is only translational degrees of freedom are designated at its four nodal points, and no rotational degrees of freedom are considered.

As the external forces increase, the element is examined whether buckling occurs or not. Buckling of this element is assessed by biaxial normal and shear stresses in the central cross-section, neglecting in-plane bending stress regarded as small.

Once the buckling interaction function$\boldsymbol{\Gamma B} = 0$ is satisfied, the element buckles and consequently the in-plane stiffness of the element decreases. This is calculated by evaluating the effective width after buckling. The effective moduli of elasticity and rigidity of this element are evaluated considering the element as a membrane. A further increase in load causes yielding at a point of the element. As Mises' yield condition was adopted as the plasticity condition, $\boldsymbol{\Gamma_Y}$=0 is expressed by stresses and is checked at four points: One at the middle of each half buckled wavelength along each longitudinal edge and one at the middle of breadth of the plate. At the point where the plasticity condition is satisfied, a plastic node is introduced. The elastic-plastic stiffness matrix can be derived according to the plastic node method. The usefulness of the element, short computing time for execution and high accuracy of the result were demonstrated by comparison with the result of the FE analysis [83]. It should be commented that the buckling interaction function and the effective width for this element were formulated by a complex intelligent work based on numerous computational results and experiments.

This element was further improved taking the behavior of post-ultimate strength into consideration [84] with Abdel-Nasser.

To propose an element of the 2nd generation, Ueda payed special attention to the following points: [85-87]:

(1) To eliminate such complex theoretical derivation process as that of the ISUM plate element (RP element) of the 1st generation.

(2) To reconstruct the framework of ISUM's theoretical basis to a similar one of the conventional FEM. This might help treat new ISUM elements as ones of the family of FEM and widen its applicability.

Therefore, it was proposed that the buckling deflection shape of a rectangular plate be adopted as a deflection function. The assumed function is composed of several component functions, one for each buckling mode, such as bi-axial compression, shear etc. The ratios between the coefficients of these components are determined so that high accuracy is obtained. Each deflection function component, representing one buckling mode, has only one free parameter to be determined. When adopting two modes of buckling, only two free parameters need to be determined. These unknown parameters are determined using the energy theorems.

In this idealization, the degrees of freedom of the element are the in-plane displacements of four nodes and one or two additional free deflection parameters. Using the assumed deflection function, the stiffness matrix accounts for the large deflection effect. In this second development, the theoretical process is completely similar to the FEM. This idealization allows the analysis of non-linear behavior using these large elements (plate panels each surrounded by four stiffeners). Consequently, compared to the traditional FEM, the total number of degrees of freedom in structural models and the enormous computation time are significantly reduced [88].

In 2002, a new rectangular plate element of the 3rd generation was proposed by Fujikubo and Kaeding [89]. The improvement of the element was made in two ways:

Firstly, a plate panel was subdivided into several ISUM plate elements in order to cope with local yielding and collapsing during post-buckling behavior. Secondly, new shape functions of deflection were introduced in the subdivided area based on the collapse modes. This new element demonstrated good applicability to deal with buckling, post-buckling and even local yielding of a rectangular plate. This treatment made a significant improvement in the accuracy of the ultimate strength and collapse strength including the behavior such as the load-shortening relationship after the ultimate strength attained.

(4) Stiffened plate element

Based on the rectangular plate element of the 1st generation, a rectangular stiffened plate element was developed [81, 82] with Rashed and Paik. The element is surrounded by four large supporting members such as deck girders and beams in the supertanker structure. It is furnished with n-number of stiffeners along one direction. Considering continuity of the overall structure, and the presence of large supporting members at the element edges, the element is considered to be simply supported along its four edges which remain straight during deformation. It is assumed to be subjected to bi-axial normal and shearing stresses in its plane.

As the load increases, the behavior of this element splits into two different types, depending on whether it buckles or not. As the first case, buckling of this element may occur in overall or local mode, depending on the stiffness of the stiffeners. Buckling should occur at the smaller of the two buckling loads in these two buckling modes. First, when the element buckles in the overall buckling mode, the element is treated as an orthotropic plate, and its behavior is represented in an incremental form by the nodal forces and displacements at four nodes set at the four corners. On the other hand, if local buckling of plate panels between stiffeners occurs, the element is treated as a set of stiffeners and plate panels with effective breadth.

After over-all buckling, the onset of plasticity is detected by the stresses at the eight points (four corners and four mid-edge points) in the same way as the rectangular plate element, At a yielded point, a plastic node is introduced, and the elastic-plastic stiffness matrix is derived according to the plastic node method.

In the case when local buckling occurs, ultimate strength is reached by either buckling or yielding of the equivalent beam-columns, composed of the stiffeners and the effective width of buckled plate panels.

When a stiffened plate does not buckle in either local or overall modes, it reaches its fully plastic strength. The buckling, ultimate and fully plastic conditions were expressed in explicit forms and the usefulness of the method was demonstrated with examples.

Another ISUM stiffened plate element was developed, by modelling the stiffeners by beam-column elements and plate panels by ISUM plate elements [89] by Fujikubo and Kaeding. Out-of-plane displacement is added to the nodal displacements of the plate element and the large deflection effect due to overall stiffener buckling is taken into account. It was shown through a comparison with the FEM analysis that the ISUM stiffened plate model can accurately predict the post-ultimate strength behavior of a continuous stiffened plate under in-plane forces, which is accompanied by the locally confined plastic deformation. Consequently, the load-shortening relationships is also accurately predicted.

(5) Complimentary plate element and modelling of double bottom structure

Double bottom structures are used in ships, as well as marine and land structures. When a double bottom structure is subjected to external load, local buckling and/or local yielding may take place. For ultimate strength analysis of such large complicated structures, the ISUM was applied.

This double bottom structure was idealized as a grillage structure surrounded by longitudinal and transverse girders, with the top and bottom covered by flat plates.

This flat plate was treated as an ISUM RP element. The stiffness matrix of this RP element can be derived by the standard procedure and the resulting matrix was divided into two parts. One part corresponds to the stiffness for normal stress components, which is included in the stiffness of flange of the girder elements with an appropriate plate width, e.g. full width. The other part is the stiffness that represents the effect of Poisson's ratio in an in-plane stresses and in-plane shearing stress. The plate element for the latter role was called a complementary element.

Then, the double bottom structure was regarded as an assembly of the girder elements (composed of webs and flanges) and the complementary plate elements [90] with Katayama.

Nodal points are designated at the four corners of each horizontal plate and at the mid-depth of each vertical web of the girder element. Utilizing the continuity of displacements, the nodal displacements at the four corners of each horizontal plate were expressed by those at the mid-depth of the web of the girder element. Thus the behavior of this structural unit was described only in terms of those nodal displacements at the mid-depth.

When the girder elements exhibit local failures. This was handled as described in 4.4 (1).

On the other hand, the inner and bottom shell plates of the double bottom of a ship, are subjected to several kinds of loads. As a result of careful consideration, it was assumed that the horizontal plate is subjected to uniform compressive loads of different magnitudes in two directions. Buckling and post-buckling behavior of the horizontal plate was analyzed by the analytical method.

According to the finite displacement theory with a stress function F and deflection w, and solving the equilibrium equations, the stress function and the buckling interaction function Γ_B were expressed in explicit form and $\Gamma_B = 0$ is the buckling condition. Using the stress function F, average stress and strain, and force and displacement relations for the post-buckling behavior were derived. From these relationships, it was possible to express the rigidity of the element that decreases after buckling. Its effect might be expressed by replacing the elastic modulus with effective elastic moduli in two direction. The stiffness matrix of the element could be derived based on this idea. In this treatment, it was assumed that the shear stiffness is the same as the value before buckling.

The ultimate strength of a cross-section of the girder element may be obtained by performing necessary modification on the ultimate strength interaction relationship of the original one. Local failures are detected according to the nodal forces acting at the node located in the section. The treatment of ultimate strength interaction is the same as that for the original girder element.

When it is judged that the horizontal plate has reached the ultimate strength at the nodal point, the stiffness matrix of the horizontal plate corresponding to that state may be derived based on the plastic strain incremental theory by regarding the ultimate strength correlation as the plastic potential. The average stress-strain matrix and the stiffness matrix of the horizontal plate element can be derived according to the usual procedure. They are divided into two parts, of which roles were the same as described before. Considering these roles, new stiffness matrix may be derived.

An ultimate strength analysis of a model of the double bottom structure was performed. The results exhibited good capability of the method to trace details of different phenomena such as local buckling and local yielding within a very short computing time [91].

4.5 Ships and offshore structures under special loading conditions

（1）Dynamic response of oilrig under collision

When designing oil rigs that operate in the ocean, collisions with supply boats, the resulting damage, and their influence on the remaining strength of the structure are major issues to consider. Also, oil rig-water interactions and ship-water interactions need to be considered.

The primary objective was to provide a fundamental strategy to understand the dynamic response of offshore structures under collision. To design offshore structures against possible accidents, comprehensive understanding of the structural response under collision is necessary.

Depending on the structural type and dimension of the oilrig and the speed and the mass of colliding body, resulting damage can vary from local denting of a tubular member to permanent deformation extending to several members. As the first stage, denting and bending deformation of simply supported tubular member under collision was investigated both experimentally and numerically with Murakawa [92] [Award 3].

When offshore structures are collided with supply boats, the damage or the plastic deformations are limited within the collided members in most cases. The supporting structures which support the collided member only oscillate and dissipate colliding energy elastically. Though no damage is caused in themselves, the dynamic characteristics of the supporting structures are very important to study the motion of the collided member and to predict the damages. To clarify the dynamic characteristics of the supporting structures, modal synthesis was employed. Once parameters characterize the supporting structure are extracted, the response of oilrig under collision can be replaced with that of an equivalent spring-mass system with three degree of freedom [93]. The influence of relative speed or the duration of the collision on damage and that on residual strength were also studied [94].

When an offshore structure is damaged through a collision with a ship or an iceberg, certain influence from the fluid force acting on the colliding body is expected. The characteristic of the phenomenon changes with the relative speed of collision, in other words, it depends on the relative duration time of collision. In general, the duration time is determined not only by the mechanical property of the collided structure, such as its stiffness and strength, but also the shape and the mass of the colliding body.

To obtain general view of the phenomena for both cases when the behaviors of the structure are elastic and elastic-plastic, the effects of the fluid force under collision were investigated through experiments and numerical analyses. It was shown that the effect of fluid force can be classified by parameters which represents the relative duration time of the collision. When duration time is relatively long, the contribution of the fluid force in collision increases [95], [Award 4] with Murakawa and [96] with Xiang.

(2) Jack-up Rigs in Survival and Punch-through Conditions

The ultimate strength is one of very important criteria for safety assessment of offshore structures. In 1987, Rashed evaluated the ultimate strength of jack-up rigs by using the ISUM. Two loading conditions were taken into account, i.e. survival and punch-through conditions, which might lead to total collapse of the rigs [97].

From the investigation, the following conclusions were drawn: (1) Two types of failure mechanism is distinguished, i.e. yielding of chord which occurs usually with fixed type jacking units, and buckling or yielding of braces which occurs usually with floating type jacking units. (2) In the case of jack-up rigs dealt in the study, the maximum wave force in survival condition is 1.6-1.8 times of the design extreme wave load and allowable penetration in punch-through condition is 4 ~5m. This is believed to be typical for jack-up rigs. However, the present design may not be considered overly conservative, taking into account many uncertainties involved. (3) In three legged jack-up rigs, failure of one leg would lead to total collapse of the rig. No redundancy is provided by the other two legs.

Based on these conclusions, a simple analytical model was developed and simplified formulae were proposed to estimate the ultimate strength of jack-up rigs under the above mentioned two loading conditions according to the failure mechanism and the type of jacking unit.

(3) Double bottom stranded on a rock

Ueda studied the collapse behavior of double-bottom structures due to stranding [98]. The ISUM was applied to the analysis and a double bottom structure was modeled using ISUM's deep girder elements and complementary plate elements. In order to gain information to enhance the ISUM's ability to deal with the special loading conditions of a ship's stranding, model experiments were conducted to investigate the process of structural damage caused by stranding. A 1/7 scale model of double bottom structure in a hold of a 120 m LBP general cargo ship was tested until collapse.

The following conditions were assumed for the ship's stranding phenomenon. At high tide, the bottom of the ship runs aground at the center of the double bottom. Then the sea level slowly drops to low tide. Therefore, the process is considered static. Consequently, a ship is subjected to the reaction force from the rock and the distributed loads induced by the change of buoyancy. The relationship between the reaction force and the change of draught must be satisfied simultaneously in the equilibrium state, taking into consideration of the deflection of the ship. The analysis of a stranded ship consists of the evaluation of external loads acting on the ship and that of the response of the ship.

As the shape of a stranding rock was assumed to be a cylinder with a flat top, the double bottom structure was subjected to highly concentrated load at cross-sections of the webs (floors and girders). Then, a large deformation of the structure occurred in the limited part in contact with the rock. As the load increased, the most loaded parts, such as floors and girders, buckled and folded, forming a collapse mechanism. At the same time, direct compressive load was acting to the webs through the bottom plate in the loaded area. Then, local compressive buckling of the webs occurred. In this study, this buckling was assumed to take place after the collapse of floors and girders, and the buckling load R_{cp} was estimated by an empirical equation.

Under further load increment, the plastic membrane force was generated in the bottom plate of the ship and the vertical component of force was evaluated from the geometry. This force was an additional strength of the structure after a collapse mechanism was formed. The action range of the membrane force expanded as the load increased. When the membrane strain induced in the bottom plate reached the rapture value in one direction, the resistance force immediately decreased. Then, the membrane in another direction resisted and reached its limit to rupture. Then, the model reached its ultimate strength. The rapture strain was assumed 0.2. Based on these information, the complex behavior was idealized and additional capability of the ISUM was developed.

Theoretical calculations were performed with this newly improved analytical method. The accuracy of this analysis was confirmed by comparing it with the results of experiments.

Next, by applying this analysis method with the expanded function, the stranding strength of the 120 m LBP actual commercial cargo ship was analyzed. In order to take into account of the effect of manholes of girders and floors, their mechanical behaviors such as effectiveness of the webs with manhole, buckling interaction relationships, effective tension field, etc. were idealized and added to the method. The accuracy of the method was confirmed by comparing with results of the experiment. With this methodology, a stranding strength analysis for an actual ship was carried out and it was recognized that the method should be a useful tool.

（4）Ductile fracture of ship at collision

In most cases of collision between ships, a ship bow is colliding into the side hull of another ship. To estimate the damage on the double hull of the collided ship, a set of experiments on scaled models and the FE analyses were conducted. In this research, the initiation of a ductile crack from a position with high stress concentration and its growth in collision state were closely investigated [99] with Tanigawa.

To obtain a criteria for crack initiation and propagation, experiments on scaled models with stress concentration introduced by a circular notch and by a stiffening member welded on the base plate were conducted. At the same time, the FE analyses were performed. For the case of crack initiation, tensile tests of wide plate specimens including structural discontinuity to realize strain concentration and multiaxial stress state were performed. For the case of crack propagation, tensile tests of pre-strained wide plate specimen were conducted considering the stretch of side shell plate caused by the ship bow penetration.

Based on the result of investigation, for crack initiation a criterion was proposed that the averaged through thickness value of ductile damage parameter was 0.5 or the equivalent plastic strain was 0.45 for SS400 plate. For crack propagation reduced values of CTOA (crack tip opening angle) due to pre-strain were obtained and the corresponding values of equivalent plastic strain were computed taking account of the size of finite elements. Applicability of the proposed method was examined by a ship side structure model test.

4.6 Usefulness of ISUM demonstrated by successors

The analysis methods based on the ISUM was further developed by a successor, Fujikubo, and demonstrated the usefulness of the method with examples.

(1) Collapse analysis of ship's hull girder

Firstly, in 2005, the ISUM was applied to analyze the progressive collapse of a frigate model subjected to bending [100] by Fujikubo with Pei. The model was a 1/3-scale welded steel frigate model (L= 20M) and made by welding. The experiment was conducted at Naval Research Establishment, Dunfermline, UK on the model in sagging condition produced by four-point bending [101]. The test result revealed that overall collapse was accompanied by buckling/plastic collapse of deck, side and bottom structures. The model of one transverse frame space was analyzed by the ISUM and ABAQUS. The results of these two analyses showed that resulting collapse modes and moment-curvature relationships were in good agreement. The obtained collapse behaviors were also consistent with the test results. Judging from these results, the ISUM stiffened plate elements developed with consideration of the local plastic deformation can predict the progressive collapse behavior of a ship hull structure under pure bending with a good accuracy.

The ISUM was further extended for the collapse analysis of a whole ship in waves. To predict a full collapsing process of a ship's hull girder in waves including failure extent and associated risks, a coupling analysis on motion and collapse is needed with consideration of fluid-structure interaction and dynamic effects. A total system of hull girder collapse analysis was developed by Yao, Fujikubo, Iijima and Pei, by coupling the ISUM for collapse analysis and the SSODAC by Iijima for motion/load analysis [102]. A series of time-domain collapse analyses of a bulk carrier was performed for different loading conditions, and details of the collapse behaviors were provided including the residual failure extent and stresses. The CPU time required for the ISUM analysis for one loading condition was about 30 min on the server having 12 Cores with 3.6GHz CPU and 32GB memories, while that required for the conventional FE analysis was 35 hours. With increasing needs for the quantifying risks of structural failure of ships under extreme and abnormal conditions, the ISUM system will undoubtedly become a reasonable and practical method of collapse analysis of a ship hull girder.

(2) Very large floating structure

In 2005, a very large floating structure was analyzed successfully by the ISUM [103]. The model was an international floating airport 5000m long. The external loads were estimated from the hydro-elastic response analysis of the model in waves, which includes dynamical effects, and were applied to the structure in a quasi-static manner. The result predicted that the spread of collapse region on the stiffened panel in the bottom was over more than 200m width of area under a specified large wave condition. These example analyses demonstrate the excellent applicability of the ISUM.

4.7 Summary- Computational Structural Mechanics, specifically for ultimate strength analysis.

Professor Ueda used the excellent performance of the FE analysis method to thoroughly analyze the behavior of rectangular plates and stiffened plates under in-plane forces up to the ultimate strength together with Yao. Based on the results of this analysis, important information on structural design was provided. At the same time, it was recognized that the FEM was a very powerful tool, but time consuming.

To realize Ueda’s research dream of analyzing the behavior of structures up to the ultimate strength, which should have required huge computational resources and time, he had to develop new analysis methods. In order to overcome these problems, Ueda introduced the concept of idealization and proposed the ISUM (Idealized Structural Unit Method). Several ISUM elements for the analysis of plate structures and also frame ones were developed with Rashed.

Paik and Fujikubo who were once students of Professor Ueda, independently developed this analysis method further. Recently, Fujikubo has extended the capabilities of this analysis method in analyzing the strength of ship hull taking into consideration of the interaction between fluid and structure, and dynamic effects.

The mathematical system of the most recent ISUM is just compatible to that of the conventional FEM and the most important assertion of the ISUM is an analyzing capability with a very high speed maintaining reasonable accuracy.

The ISUM has its basis on an idealization of nonlinear structural collapse behaviors into simple structural models through a deep insight into the essential cause of local failures. It can therefore provide the designer with not only efficiency but also an easy way to grasp and predict the complex collapse behaviors.

Today, a computational power has enormously increased, but the required effort is still large for the case of large plate structures. With increasing need for the limits state or risk-based design approach to ships and offshore structures, the ISUM is believed to play an important role as a practical design method.

Prof. Ueda was involved in various academic activities other than research in the field of structural mechanics as well as welding mechanics.

In 1977, Prof. Ueda was invited to Department of Naval Architecture and Marine Engineering, the University of Michigan, U. S. A. for one year and lectured on “Strength of ship structures” to undergraduate students” and “Plastic analysis of steel structures”for graduate students.

He had participated in research activities of the Society of Naval Architects, Japan (SNAJ) for many years and he became a member of Board of Directors from 1987 to 1989. Later he was nominated as a Meritor of the Society. At the occasion of the Centennial Celebration of the Society in 1997, he received the contribution award [Award 7].

In 1998, Prof. Ueda was awarded the Shipbuilding Technology Award (Yoshiki Award) [Award 8] from the society (SNAJ) for his great longtime contribution through many invaluable re-searches.

From 1979 to 2000, he participated in the activities of International Ship & Offshore Structures Congress (ISSC) as a member of Technical and Standing Committees, representing Japan. Relating to ISSC, he served as Editor of International Journal of Marine Structures from 1988 to 1997.

He was Associate Editor of ASME Journal of OMAE (Offshore Mechanics and Arctic Engineering) from 1983 to 1990. Alongside this, he was also the Associate Editor of the Journal of Applied Mechanics Reviews ASME. He participated in the establishment and development of the International Society of Offshore and Polar Engineers (ISOPE). He hosted the 3rd ISOPE Osaka Conference in 1994. He was a member of the board of directors from 1995 to 1999 and President of the society from 2000 to 2002. In 2007, he gave a commemorative lecture in honor of the J. S. Chung Award for outstanding creative and innovative contributions [Award13]. In 2015, he received Neptune ISOPE Award for his selfless dedication and contribution [Award 14].

Professor Terazawa was the chairman of the Japanese Technical Committee of Det Norske Veritas (Norwegian Classification Society) for the exchange of views on technical issues between the Japanese shipbuilding industries and the DNV for many years. Prof. Ueda served as Secretary and later he took over the responsibilities of chairman from 1988 to 2000.

He was awarded an honorary doctor from the Norwegian University of Science and Technology in 2002 [Award 12]. Prof. Paik organized the 35th OMAE 2016 Conference and dedicated to Prof. Yukio Ueda the Honoring Symposium on Idealized Nonlinear Mechanics for Welding and Strength of Structures [Award 15].

5. Concluding Remarks

Professor Ueda proposed several computational analysis methods in idealized nonlinear mechanics for welding and strength of structures. Specifically, there are the following two main analysis methods. They are Computational Welding Mechanics (CWM) and Idealized Structural Unit Method (ISUM). The former has been already established as a standard analysis method including innovative applications of the inherent strain method. The latter embodies the engineering and innovative idea of idealizing and analyzing the nonlinear behavior of structures and is recognized as a very useful tool for engineering purpose. These two methods are the computational methods for comprehensive analysis of structures from construction stage to structural collapse stage. Significance of these research works exists in integration of the two different disciplines into a cross-disciplinary and innovative research fields. This forms an essential basis for the idea of design by analysis and production planning based on computational simulation.

In this sense, he is the pioneer on these subjects.

The concept of idealization has a potential to expand in other fields to allow efficient and accurate analysis of different phenomena.

Observing his research life, his attitude toward research seems to be as follows:

When he was engaged in the research projects, he tried to get solutions in most fundamental forms. In other word, he tried to obtain a kind of master key, which could be used for a wide range of similar problems, instead of individual solutions. To achieve this goal, he had to study deeply the fundamental nature of the problem from various aspects and understand the characteristics of the phenomena. In the process of investigation, he was playing with it by changing boundary and loading conditions. The phenomenon seemed to him as if it were the reaction of a kind of creature and became a good friend of his. How much to understand it is dependent upon his ability and sensitivity. Once he grasped its character at his utmost effort, he came up with some good ideas for solutions. Therefore, other researchers may figure it out differently and find several different types of solutions. This depends on the inherent capability of individuals. His solution may be very common sometime and peculiar in other time. If the peculiar idea has a wide range of applicability and rationality, it is believed to be a new theory or an innovative method. If not, it must be understood simply as a unique way of thinking and its application must be very limited. When he tried to solve a research subject using various methods, he sometimes hit the wall and could not get solutions. At that time, he encouraged himself by saying he had finally found a gemstone of a new solution.

He expressed his deep appreciation to his colleagues recognizing that he could not conduct research for many years without their constructive cooperation. He was very grateful to have had such a lucky life as having met many people, had many opportunities, and received much advice and help.

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Awards:

Award 1, 1973: The Best Paper Award from the Japan Welding Society (JWS) to Analysis of Thermal Elastic-Plastic Behavior of Metals during Welding by Finite Element Method.

Award 2, 1974: The Best Paper Award from the Society of Naval Architects of Japan (SNAJ) to an Ultimate Transverse Strength Analysis of Ship Structure.

Award 3, 1990: The Outstanding Paper Award (OMAE Award) from the American Society of Mechanical Engineers to Classification of Dynamic Response of a Tubular Beam under Collision.

Award 4, 1992: The Best Paper ISOPE Award from the International Society of Offshore and Polar Engineers to Effect of Fluid Force Acting on the Colliding Body upon the Elastic-Plastic Response of an Offshore Structure.

Award 5, 1993: The Scientific Engineering Prize from the Okada Memorial Japan Society for the Promotion of Welding (OMJSPW) for a Great Achievement of Theories for Analysis, Prediction and Measurement in Welding Mechanics.

Award 6, 1995: The Academic Contribution Award from the Japan Welding Society (JWS) for A Great Contribution to Welding Engineering through Development of Principles and Theories of Computational Welding Mechanics.

Award 7, 1997: The Contribution Award from the Society of Naval Architects, Japan (SNAJ) at the Occasion of the Centennial Celebration of the Society for a Great Longtime Contribution to Development of the Society.

Award 8, 1998: The Shipbuilding Technology Award (Yoshiki Award) from the Society of Naval Architects, Japan (SNAJ) for a Great Longtime Contribution to Development of Shipbuilding Technology through Many Invaluable Researches on Theoretical Analyses of Ships and Offshore Structures.

Award 9, 1999: The SNAJ Award from the Society of Naval Architects, Japan (SNAJ) for the Invention of Automatic Line-Heating Plate Bending Machine.

Award 10, 2000: The IIW Yoshiaki Arata Award for Outstanding Achievement in Fundamental Research in Welding Science and Technology (IIW: International Institute of Welding).

Award 11, 2001: The JSPMI Award from Japan Society for the Promotion of Machine Industry for Striking Originality in Development of Labor-Saving Automatic Plate Bending System by Line-Heating for Shipbuilding.

Award 12, 2002 : Honorary Doctor of Engineering from Norwegian University of Science and Technology, Norway.

Award 13, 2007: J S Chung Award from the International Society of Offshore and Polar Engineers (ISOPE) for Outstanding Creative and Innovative Contributions to the Offshore, Ocean and

Polar Engineering Fields.

Award 14, 2015： Neptune ISOPE Award from International Society of Offshore and Polar Engineers (ISOPE), In recognition of his selfless dedication and invaluable contribution to and leadership in the establishment and growth of the Society and to its conferences and symposia.

Award 15, 2016: Prof. Yukio Ueda Honoring Symposium dedicated in the 35th OMAE, 2016 Conference, American Society of Mechanical Engineers (ASME). The title of the symposium is Idealized Nonlinear Mechanics of Welding and Strength of Structures.

Abbreviation
ASME: American Society of Mechanical Engineers
DCAMM: The Danish Center for Applied Mathematics and Mechanics
FEM: Finite Element Method
IIW：International Welding Institute
ISOPE: International Society of Offshore and Polar Engineers
ISSC：International Ship Structures Congress
ISUM: Idealized Structural Unit Method
JASNAOE: Japan Society of Naval Architects and Ocean Engineers
JSPMI: Japan Society for the Promotion of Machine Industry
JWRI；Welding Research Institute, later changed to Joining and Welding Research Institute,
JWRIAN: Name of software developed at JWRI
JWS：Japan Welding Society
OMAE: Offshore Mechanics and Arctic Engineering
OMJSPW: The Okada Memorial Japan Society for the Promotion of Welding
PRADS: Practical Design of Ships and Mobile Units
SNAJ: Society of Naval Architects, Japan
WSE：Welding Science and Engineering