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THE BTM-CONCEPT - AN EXPERIMENTAL METHOD TO SIMULATE THE BEHAVIOR OF SUBSTRUCTURES CONSISTING OF TRUSS OR BEAM MEMBERS

Wolfgang MAIER[1] and Allen J. CLARK[2]

[1]Scientist, Inst. of Steel Const., Technical University of Braunschweig, FRG
[2]Division Manager, MTS Systems Corporation, Minneapolis, MN., USA

SUMMARY

A new static 6 degree of freedom load unit testing machine is described. The concept allows flexibility in configuring tests without dedicated design fixtures and restraints. It can be used to: 1) verify theories and models of complex substructural behavior; 2) perform hybrid simulations when part of the structure can be modeled on a computer and a complex interacting substructure tested, and 3) perform basic constitutive data gathering of the 6 degree of freedom load-displacement properties when they are unknown for a specimen.

SIX DEGREE OF FREEDOM LOAD UNITS (6DF-LU)

The essential part of the BTM Testing System is the Six Degree of Freedom Load Unit which consists of a Six Degree of Freedom Actuator (6DF-AC) and a Six Degree of Freedom Load Cell (6DF-LC). A 6DF-AC consists of a load plate where the specimen is to be fixed, an abutment plate for fixing the 6DF-AC on the test rig, and a drive unit in between, which moves the load plate against the abutment plates. The drive unit may be built using six servo hydraulic actuators in canopy configuration, as seen in Figure 1a. Where a single actuator provides a single force, the 6DF-AC provides six forces (see Figure 1b): the shear forces F_1 and F_2, the axial force F_3, the bending moments F_4 and F_5, and the torsional moment F_6. This can be done by moving the load plate against the abutment plate with the six degrees of freedom, i.e., the six displacements $D_1 .... D_6$, corresponding to the six forces $F_1 .... F_6$. The 6DF-AC includes a measurement system for the six displacements. Therefore, it is possible to control the six displacements or the six forces of a 6DF-LU.

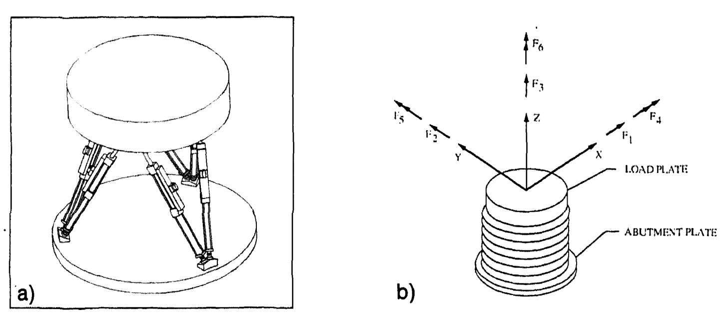

Figure 1. Six Degree of Freedom Load Unit (6DF-LU)

6DF-LU as Loading Device for External Forces and Displacements. For load testing specimens in a free testing arrangement, single hydraulic actuators are often used. The designer of the testing arrangement is faced with the problem of keeping the acting line of the forces in the required position during the test. The difficulties are caused by the deformation of the test specimen, especially for large deformations. The simple example of the frame in Figure 2 may show the problem. The acting point A for the forces F_1 and F_2 is required to remain plane. Therefore, a lateral support is necessary. For applying the forces F_1 and F_2, a testing arrangement according to Figure 2 is common.

A roller is placed between the vertical actuator and the base. With the help of an auxiliary actuator, the acting line of F_1 can be kept vertical. Analogous to this configuration a bi-directional roller may be used for the force F_3.

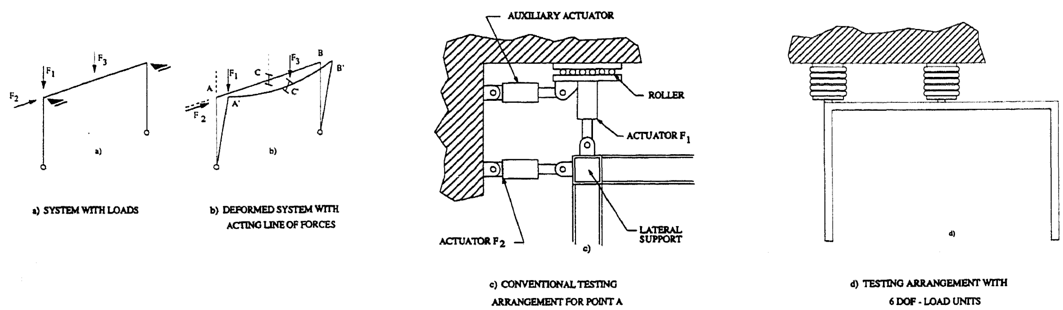

Figure 2. Example for Required Acting Lines of Forces

A testing arrangement with the 6DF-LU requires one load unit for point A and one for point C without additional provisions for acting line control and lateral support. It is important to emphasize, that the acting point of the forces F_1, F_2, and F_3 may be elsewhere in the specimen; they are not determined by hinges outside the specimen, as is the case for the conventional testing arrangement.

6DF-LU as a Loading Device for Internal Forces. The BTM system has been developed as a device for testing substructures consisting of truss or beam members. Figure 3 shows a multi-story frame as an example of such a structure. The test specimen or substructure may be a single column, a plane, or a spatial connection. Simulating the structural behavior of the test specimen (substructure) within the structure means moving the end sections of the specimen (intersection between structure and substructure). This can be done with the help of 6DF-load units (see Figure 4), the end sections of the specimen are rigidly fixed on the load plates of the 6DF-LU.

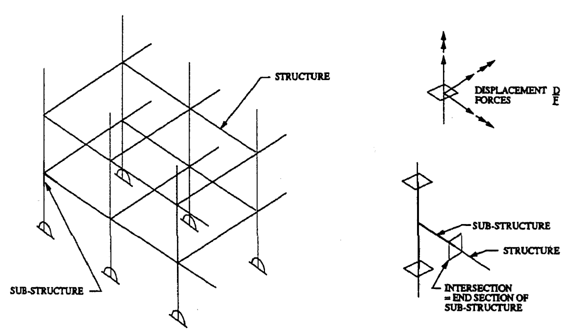

Figure 3. Structure - Substructure and Test Specimen

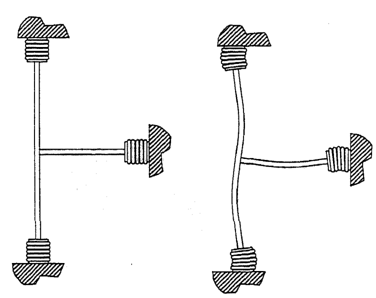

Figure 4. Testing Arrangement with 6DF-LU's

TEST MODES

It is useful to distinguish between three test modes with respect to the purpose of the test:

a) Verification Mode - A theory (mechanical model) for describing the structural behavior of a structure is available, but needs experimental evidence.
b) Communication Mode - The available theory applies for the structure except for a small part (substructure). The behavior of this substructure within the structure shall be obtained by experiment.
c) Stand Alone Mode - Only the structural behavior of a substructure is of interest. It shall be obtained in general by experiment.

Verification Mode. Instead of testing the whole structure, BTM-Testing System allows testing of suitable substructures. The procedure may be the following:

a) Using theories, the displacements D_c and forces F_c for the intersections between structure and substructure due to the loads acting on the structure are calculated.
b) These displacements D_c are imposed on the specimen and the resulting forces F_t are measured in the test.
c) Comparison of calculated forces F_c and the forces F_t obtained in the test gives a basis for evaluating the theory.

Communication Mode. The test specimen is related to the substructure, whose structural behavior is unknown. For the static case, this behavior with respect to the interaction between substructure and remaining structure may be described by the actual stiffness matrix K_s. The procedure is the following:

a) Calculating of the displacements $D_c^{(1)}$ and forces $F_c^{(1)}$ according to the theory for the first small load step. For the stiffness matrix $K_s^{(1)}$, an estimation is used.
b) These displacements $D_c^{(1)}$ are imposed to the specimen and the resulting forces $F_t^{(1)}$ are measured.
c) The obtained information given by $D_c^{(1)}$, $F_c^{(1)}$, $F_t^{(1)}$, and $K_s^{(1)}$ is used to improve the stiffness matrix $K_s^{(1)}$ to $K_s^{(2)}$ for the second load step.
d) Calculating of displacements and forces for the second load step and so on.

Calculation and testing are simultaneously performed; the communication is with respect to the stiffness matrix.

For simulating dynamic effects, the communication mode becomes the pseudodynamic test technique. The BTM concept has potential for improving the performance of pseudodynamic tests.

Stand Alone Mode. The stand alone mode is the most common test mode for experimentally obtaining information on structural behavior. Displacements and forces acting on the end section of the specimen are predescribed and usually given in terms of boundary conditions, load conditions, and load histories for the independent loads as shown in Figure 5 (load in this sense covers both forces and displacements). Boundary conditions may be given as hinges (force F_i=0, e.g., bending moment F_{11}=0), as rigid restraints (displacement D_i=0, e.g., horizontal displacement D_1=0) or as springs (force F_i depends on displacement D_i, e.g., spring constant C_7 with $F_7 = C_7 D_7$). Load conditions may refer to acting lines of forces (e.g., F_8/F_7 =constant) and load histories may be described by time functions of forces or displacements (real time or only pseudo time).

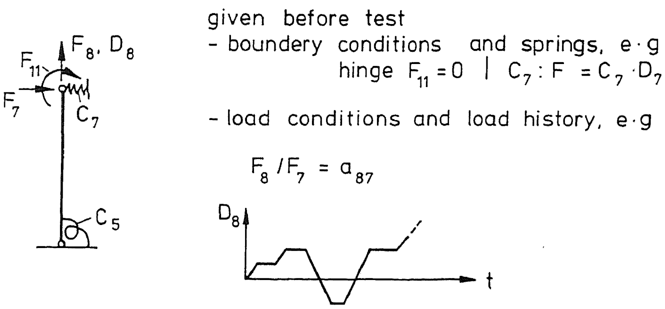

Figure 5. Boundary Conditions and Load Conditions for Stand Alone Mode

<u>BTM Testing Machine and Free Testing Arrangement</u>. A testing machine for a two-ended specimens, e.g., columns, requires one 6DF-LU. For such specimens, it is useful to split up the necessary 6 degrees of freedom and to use e.g., two 3DF-LU instead of one 6DF-LU, as Figure 6 shows. This will improve the machine's stroke capacity.

For multi-ended specimens, usually free testing arrangements will be used. For this purpose 6DF-LU are used similarly to single hydraulic actuators in the conventional test arrangement. The 6DF-LU may be fixed on test rigs, test floors or reaction walls. In general, for an n-end specimen n-1 6DF-LU are necessary. For the sake of the displacement capacity, however, n 6DF-LU are recommended. Then, the displacements can be optimized by washing out the rigid body movement.

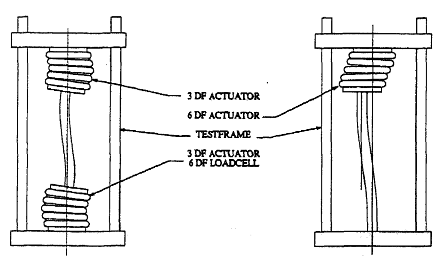

Figure 6. B.T.M. Testing Machine

EXAMPLE APPLICATIONS

The authors reviewed the Proceedings of the Eighth World Conference on Earthquake Engineering, Volume VI: Experimental Methods and Test of Structures and Components. It was found that 80 percent of the steel tests and 50 percent of the reinforced concrete tests could benefit from using the BTM arrangement.

Two examples are shown in the figures below. The first shows the test apparatus used by Matsui, Marino, and Tsuda (Ref. 1) for testing a steel cantilever column. the apparatus shown in Figure 7 used hydraulic actuators, bi-directional rollers, thrust bearings, radial bearings, and a bidirectional hinge. The second shows the test apparatus used by Nagasaka (Ref. 2) for testing steel fiber reinforcement characteristics for reinforced concrete columns. The apparatus of Figure 8 used a large bellcrank and a planar parallel mechanism.

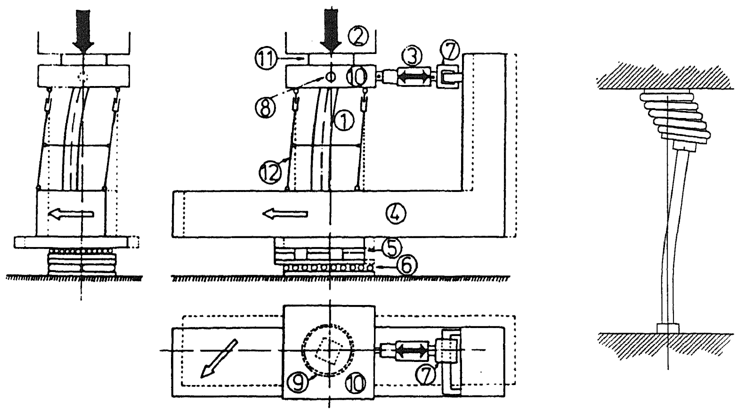

Figure 7. Test of Inelastic Behavior of Steel Beam-Columns of Box Section

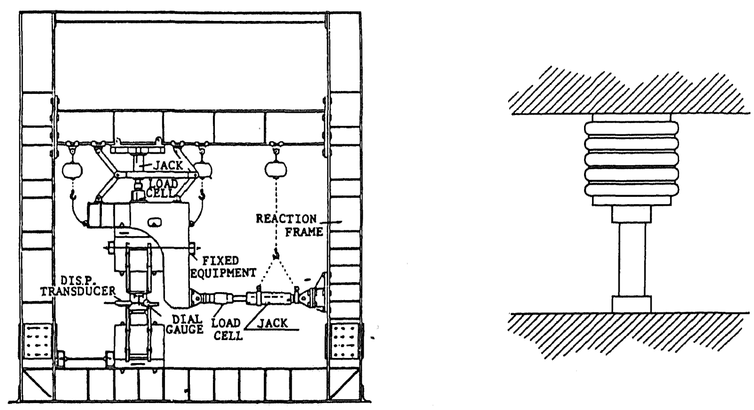

Figure 8. Test of Reinforced Concrete Column Section

CONTEMPORARY STATE OF RESEARCH ON THE B.T.M. TESTING SYSTEM

Due to the special circumstances at the University of Braunschweig, soon after the first ideas had become concrete, the university personnel had to start building a prototype testing machine with 1000 kN of load capacity for column specimen up to 7m height. The mechanical part of this machine was finished in 1985. Because this relatively large prototype machine is not very easy to handle, they decided to build a small experimental machine in order to gain experience and to prove the theory, as well as to test computer programs, measurements, and control equipment (Ref. 3,4 5, 6, 8). This experimental machine is ready, except for the Six Degree of Freedom Load Cell (6DF-LC), which is still under construction. Instead of the 6DF-LU, a simulator has been installed.

On this experimental machine, the theory and the computer programs have been examined for all the three test modes. Though the experimental machine works sufficiently well, hardware and software must still be improved. Photos 1 and 2 are pictures of the two machines.

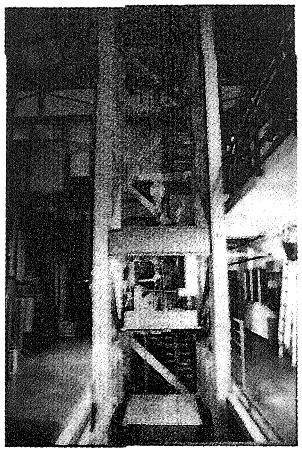

Photo 1
1000 kN Prototype

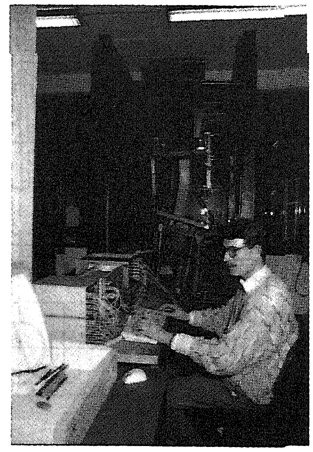

Photo 2
Instrumentation Development
Machine

ACKNOWLEDGEMENT

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