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Contract N00014-75-C-0686 Office of Naval Research

Task No. 064-514

by

Werner Goldsmith
Principal Faculty Investigator
Department of Mechanical Engineering
University of California, Berkeley

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This document constitutes the Final Technical Report of ONR Contract N00014-76-C-0686, Task No. 064-514 with the Structural Mechanics Division of that Office. The period of the contract was from January 1, 1976 to September 30, 1979. The funds provided under this contract were intended to provide a supplement to the major funding of the task by the National Institutes of Health to indicate the interest of ONR in this particular area of biomechanics.

The technical area of investigation involved the biomechanics of head injury and the biomechanics of the head-neck system under impact and impulsive loading. Theoretical models of the two types of systems were analyzed with respect to response for a known input, and experimental models were constructed and appropriately loaded so that the measured history of mechanical parameters could be compared with predictions. The analysis generally required the use of either digital computing devices or intermediate-sized minicomputers in addition to the specification of an appropriate mechanical model. The latter frequently required the determination of suitable material properties of either biological tissue or their simulating replacements for incorporation in the analytical scheme.

In particular, the following experimental models were constructed and tested:

(1) A head-neck system composed of a thin, spherical shell of lucite mounted on an artificial neck developed by General Motors Corporation and consisting of articulated steel and polyurethane segments, permitting saggital plane motion. The shell was filled with water, and the input force history, strain variations and pressure histories at various points on and inside the shell, as well as the motion of the head-neck junction were measured. Impact was produced by the contact of a ballistically-suspended hollow aluminum shell generating sinusoidal force variations with an amplitude of 286 lb and a duration of 2.5 ms.

(2) The system described was loaded as indicated and also by ½-in. diameter cylindrical projectiles with the shell filled either by distilled water, artificial cerebrospinal fluid, glycerin, or a heavy electrical condenser fluid, Fluorinert, to ascertain the generation of cavitation bubbles as the result of these impacts.

(3) A human cadaver skull was positioned on the artificial neck, supplied with in-

ternal tourmaline crystal pressure transducers suspended from the walls along a predetermined impact axis and subjected to projectile and pendulum impact on the bare surface of the skull or on various materials intending to simulate a scalp. The pressure histories and head-neck junction motion were ascertained.

(4) Another cadaver skull was equipped with a transparent occiput, placed on the GM neck and subjected to projectile impact with the cranial cavity filled with either distilled water or gelatin. Cavitation observations were executed by means of a high-speed camera and by pressure transducers.

(5) A zero- and a first-order model of the human head-neck system consisting of a cadaver head and a series of non-biological components designed to represent the structure of the neck was constructed, instrumented and tested. A very long period of development was required to produce, test, calibrate and install satisfactory force, displacement and pressure transducers. In addition to measurements of this type, framing camera observations at rates of 3000-4000 s^{-1} were executed during impact tests to both the skull and the base of the unit.

(6) Several unembalmed head-neck structures from recently deceased individuals were brought into the laboratory, rapidly instrumented and tested by pendulum impact to the forehead.

(7) Longitudinal and transverse impact on fluid-filled tubes was executed to examine the energy transfer between liquid and solid, using strain gage and immersed tourmaline crystal transducers.

(8) A number of mammalian muscles were tested under quasi-static conditions at various loading rates to examine their mechanical properties and to develop suitable constitutive equations. This process was repeated fcr several artificial compounds intended to simulate the muscles. Similar work is currently in progress on ligaments.

Theoretical and numerical studies pertaining to the investigation included:

(1) The development of an analytical model for the lucite shell and GM neck (based on an indentification of the neck properties from test data supplied by the manufacturer) capable of calculating the history of the field variables in the shell, the

interior fluid, as well as the deflection of the neck. The analysis uses transform techniques with inversion requiring numerical methods.

(2) A two-dimensional finite difference program was constructed providing predictions for the saggital-plane motion of a realistic human head/neck system subjected either to impact at the forehead or impulsive loading of the base. This program is currently being extended to three-dimensional motions.

(3) A previously-developed computer program detailing the history of stresses, strains and pressures in elastic spherical shells is being adapted to the realistic head/neck system impact situation.

Comparisons between theoretical predictions and experimental data range from reasonable to excellent. Certain computational and experimental difficulties were found to have occurred in previous investigations and the techniques involved are in the process of modification. It is expected that this program will continue for a period of at least 18 months with the possibility of renewal with an expanded scope.

The following advanced degrees were granted during the contract period with theses relating to the subject matter described:

Mr. Greg Ouligian, M.S.

Mr. Abid Khan, M. S.

Mr. Jan Reber, M. S.

Mr. Mark Nystrom, M. S.

Mr. Paul Lubock, M. S.

Dr. F. Barez, Ph. D.

Mr. M. Kabo, senior research assistant, is about to receive the Ph. D. degree on the project. In addition to those listed, Norman Harris, M. D., and Bruce Burdick, M. D., have contributed their services without remuneration. Two additional research assistants are currently employed on the project, and several undergraduate students have been engaged as engineering aides.

The following publications have resulted either directly or indirectly from the investigations described:

(1) "The Science of Biomechanics and the Role of the Engineer," Journal of Pure and Applied Science, Middle East Technical University, Ankara, Special Bioengin-

eering Issue, Jan. 1977, pp. 1-44; also, Technika Chronika (Greek), 4/1977 pp. 5-19; also, Biomechanica, Proc. Bulgarian Academy of Sciences, v. 5, pp. 85-98, 1977 and v. 6, pp. 58-75, 1978, by W. Goldsmith.

(2) "Mechanical Simulation of Human Skeletal Muscle," Proc. Annual Conf. on Engineering in Medicine and Biology, v. 19, p. 144, 1977, by W. Goldsmith and A. Khan.

(3) "Response of a Realistic Human Head-Neck Model to Impact," J. Biomech. Engineering, v. 100, pp. 25-38, 1978, by W. Goldsmith, J. L. Sackman, G. Ouligian and M. Kabo.

(4) "Some Aspects of Head and Neck Injury and Protection," Proc. NATO Advanced Study Institute on Progress in Biomechanics, ed. by N. Akkas, Ser. E, Applied Science No. 32, Sijthoff and Noordhoff, pp. 333-377, 1979, by W. Goldsmith.

(5) "Analysis of Large Head-Neck Motions," J. Biomechanics, v. 12, pp. 211-222, 1979, by J. Reber and W. Goldsmith

(6) "Longitudinal Waves in Liquid-Filled Tubes, I: Theory; II: Experiments", Int. J. Mech. Sci., v. 21, pp. 213-221, 223-236, 1979, by F. Barez, W. Goldsmith, and J. L. Sackman.

Accepted or submitted for publication:

(1) "Biomechanics: Applications, Costs and Benefits, Priorities," J. Biomech., ed. by N. Akkas, W. Goldsmith, and R. M. Kenedi.

(2) "Experimental Cavitation Studies in a Model Head-Neck System." J. Biomech., by P. Lubock and W. Goldsmith.

Annual progress reports were submitted to the Structural Mechanics Division of ONR.