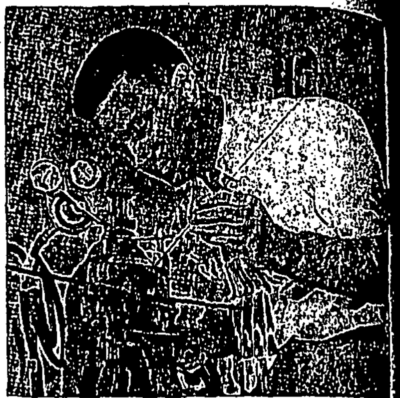
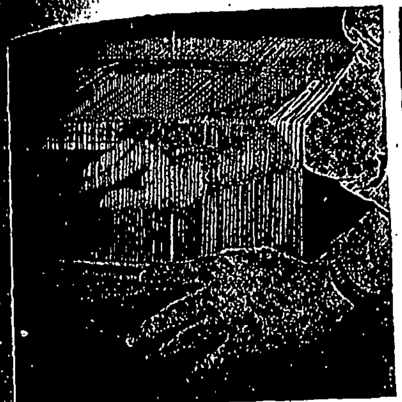
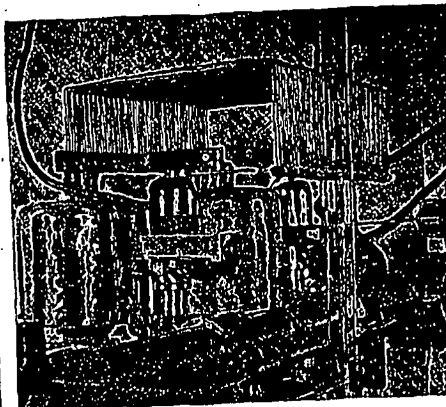
1 First step in making pipe model is to draw an isometric sketch of piping, as author does here, to fix model size



2 Brazing operation in construction of model. Cold-rolled steel rod is joined with a low-temperature brazing alloy



3 Assembly of elements in boiler superheater model. The rod elements are silver soldered to insure complete fixation



4 Closeup of model showing superheater-element section of main steam piping attached to electrical measuring units

How Model Tests Cut Piping Design and Fabrication Costs

Use of scale models to predetermine stress conditions in high-temperature piping assures economic design, good performance of modern power plants

By JOHN F O'ROURKE, *Mechanical Engineer, The M W Kellogg Co*

► RECENT TRENDS toward higher pressures and temperatures in power-plant installations have increased the importance of adequate engineering for thermal expansion. Proper design and layout of piping is essential for satisfactory service performance. Inadequate analysis in this respect has resulted in the shutdown of entire plants due to fatigue failure of piping *or distortion of connected equipment.*

Mathematical analysis of the expansion stresses and reactions is broadly covered by the General Analytical Method presented by The M W Kellogg Co in *Design of Piping Systems*, 1941. In employing this method, the solution of up to 18 simultaneous equations, which represent, in general, a system of four points of fixation, can be handled effectively. With an increase in the number of fixed ends or intermediate restraints, the mathematical approach becomes extremely laborious and time-consuming. The model test solution of piping systems has been evolved to solve problems too intricate for calculation or those where the mathematical solution is not economically feasible.

Model tests have additional appeal to designers of high-temperature piping in that they permit visual evidence of the interaction of *all* members in the system. Addition of guides or changes in configuration can be made directly on the model, and results from alternate tests readily obtained. Since alloy piping costs are a significant item in high-pressure plants, the *model tests can* be used with considerable economic advantage toward the elimination of excess piping.

Model tests have been conducted for hundreds of power, petroleum and chemical plants, and for marine installations *for the United States and British Navies. Most recently, they* have been employed for atomic-power plant design.

Principle utilized in the model test method is that of displacing the ends of the model-simulated pipeline with relation to an assumed fixed point, and measuring the end reactions created by this springing of the model. Displacements applied are a percentage of the calculated free thermal expansion of the ends from the fixed point, including the expansion of connecting equipment. The forces and moments at the ends of the model are proportional to those occurring in the actual pipeline when brought up to operating temperature.

Model Construction. *Solid cold-rolled steel rods, Fig. 2,* are used in building the model. They are bent to shape cold, and are brazed together. Model ends are silver-soldered in 1-in.-square steel blocks having tapped holes to facilitate fastening to the measuring units. The length scale used for the model depends on the dimensions of the testing apparatus and its arrangement. Most models come within a range of ½-in. = 1 ft to 1 in. = 1 ft, though some tests have been run on full-scale models of short connecting lines where operating conditions were critical.

Where the system has the same size pipe throughout, any rod diameter from ⅛ through ½ in. is used. If two or more pipe sizes are used in the actual system, their stiffness ratio is incorporated in the model. This is done by obtaining a product of the moment of inertia and the modulus of elasticity of the actual pipe and choosing rods in this relation.

Valves or similarly stiff members are represented in the model by solid steel blocks or other heavy sections. In recent years it has been a practice to include the terminal elements of the superheater as part of the piping to increase the over-all flexibility of the system. These *complicated* tube arrangements are reproduced by bending drill rod of correct stiffness to represent the tubes running to the header from the point of exit through the boiler arch, Fig. 3 and 4.

Test apparatus consists of an adjustable tubular framework for supporting the displacement units, which apply movements to the ends of the model. Machined tubular-steel posts extend from floor to ceiling of the test room, Fig. 6. To these parts, tubular arms may be attached to give access to any point within a 7-foot radius. The arms are splined to receive the micrometer displacement units.

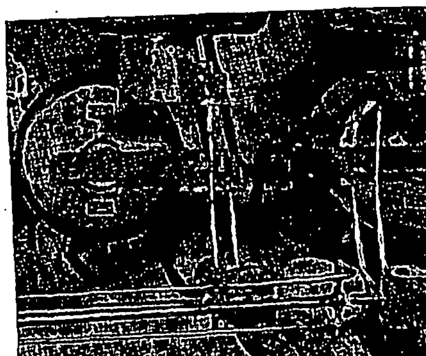
The displacement units *combine* three mutually perpendicular slides, each operated by a micrometer lead screw with a thimble graduated in thousandths of an inch.

The slideways are hand-scraped to avoid any possibility of undesired motions during application of *the displacements*. Slides are locked in position after movements have been made.

The electrical measuring units resolve the force and moment at each end of the model and measure the three coordinate components of each. This combined action is accomplished by applying the force and moment, by means of a three-dimensional cross, through six cantilevers aligned with the three coordinate planes.

Six pairs of strain gages are cemented to the cantilevers. Gage resistance varies in proportion to the cantilever deflection. Thus, by measuring the change in resistance of the various strain gages, the component *forces* and *moments* may be found. Each pair of gages is permanently wired into a wheatstone bridge circuit. A self-balancing potentiometer, Fig. 7, gives the readings directly in hundredths of a pound.

(*Continued on page 92*)



5 Turbine leads from main steam piping attached to electrical measuring units for determining system end reactions

6 General view of model test apparatus showing main steam line running from the superheater to turbine-lead takeoff