without undergoing major structural damage during repeated barrier impacts. The steel reinforcement not only made it practical to use the same test vehicle over and over again but it also permitted engineers to achieve the minimum uncontrolled variability in the experimental vehicle from one test to another.

The driverless vehicle is push-started in second gear and runs along a steel guide rail into the test barrier. For most tests the steering wheel is tied in the straight ahead position. The car's speed can be varied, the ignition interrupted and the brakes applied by remote control. A radar device is used to monitor the speed continuously up to impact.

The 400-foot cable barrier used in most tests was erected at an angle of 25 degrees to the steel guide rail. It was made up of a pair of ¾ inch steel cables carried in a slot atop 30-inch high steel posts spaced at equal distances. In addition, an identical barrier was placed at a 12½-degree impact angle for some tests.

"Post design was given special consideration," Mr. McCaffrey says. "It was felt that the prime function of the posts was to support the cable at a fixed height, to help resist cable deflection by the vehicle and, when fractured by vehicle impact or cable forces, to allow a smooth transfer of the cable to the vehicle without subsequently presenting a hazard to the vehicle and to pedestrians and other vehicles during normal traffic. We had to ensure that the posts fractured at a specific cable force and went down and stayed down. This requirement was met by notching the post at ground level.

"Tests showed that when the vehicle initially contacted the cable at a post location, the straight slots atop the posts tended to close around the cable and drag it under the test vehicle. By tapering the slots — widening the upper portion — this pinching effect was removed and the cables slid away from the posts as they were knocked over."

To measure cable tension, strain gauged dynamometers were placed at the ends of the cable which were anchored firmly in the ground. Wheel motion relative to the chassis was measured by strain gauges bonded to each of the four coil springs. An accelerometer package located at the vehicle's centre of gravity gave acceleration levels on the sprung mass (the part supported on the vehicle's springs) of the car. Some 94 test runs have been conducted, most with the reinforced vehicle. Each test lasts only a few secconds yet provides data requiring days and weeks to analyse.

Information on the translational and rotational motion of the test vehicle in three dimensions was furnished by what is believed to be a photographic first. In collaboration with specialists in photogrammetry from NRC's Division of Physics, a highly accurate method was developed for determining the path of the vehicle and for measuring its yaw, pitch and roll angles every few hundredths of a second before, during and after the moment of impact of the vehicle with the barrier. All the three-dimensional information on vehicle position and orientation needed was provided by a single movie camera. The 16mm camera used in the field trials at NRC was not specifically designed for photogrammetric purposes. However, with this photographic coverage procedure, results were highly accurate and so complete that no recourse was necessary to other sources of information on vehicle motion.

During the tests the high-speed camera, provided with telephoto lens and having a framing speed of up to 500 frames per second, was secured to a rigid platform. A set of stationary target points, made of metal discs mounted on plywood sheets, was located at some distance from the camera. The camera was placed so that the test vehicle remained visible against the background targets at all times during the tests. The sprung mass of the vehicle was fitted with a set of six target spheres (a minimum of three were required). From a careful survey of the stationary target points and the vehicle target points in selected frames of film, all six rigid body motions can be determined. A computer program was used to perform all necessary calculations and to print the results.

"Results on the vehicle trajectory and heading angle (angle which sprung mass makes with barrier), as determined from the computer, agree extremely well with those from field tests," Dr. Pinkney says. "Our barrier program appears to be functioning properly and accounting for the basic mechanism of barrier-vehicle-terrain interaction. In fact, at velocities of up to 55 miles per hour our computer results differ from field test trajectory by no more than one or two tire tracks."

"Since the BPR-CAL program contains a terrain routine for irregular profiles, we intend to use this program to simulate and study what happens when the barrier is a short distance from a deep ditch or a cliff, for example. We'll vary the slope angle and the barrier-to-ditch distance on the model and note the critical areas of the redirection process.

"With initial confirmation of our barrier model by the field tests to date, we now have a good idea of how a cable barrier behaves in general," Dr. Pinkney says. "There is no need for confirmation of each individual case, as far as the cable is concerned. The barrier doesn't know what size of car hits it or whether there is a ditch behind it; it just reacts to the vehicle surface interacting with it and we have knowledge of this interaction."

"There are many other aspects of the general problem which are not directly related to barrier and highway design," Dr. Pinkney says. "The various fender geometries, the effects of driver commands, and other aspects of the problem related to the question 'What happens if . . . . .?'. These are all amenable to simulation studies and could therefore be assessed. With the basic analysis established, the studies can be extended, in a systematic way with experiments and corresponding analysis, to investigate various aspects of the general problem."