be attributed to past growing conditions or soil variability in the test area.

In the Oroville area, the total strength increased about 25% for 4- to 9-year-old trees (284 to 363 psi) but only slightly for trees from 9 to 23 years old. Cambium strength showed the same trends as total strength and was found to be about 60 to 70% of the total strength.

An interesting result of this test was the large difference in bark strength for the same age trees in two different areas. The Oroville trees were approximately 100 psi stronger than those in the Yuba City area. A considerably drier bark moisture condition was present in the Oroville orchard, which could account for part of this difference.

Measurements of shear strength were made on French, Imperial and Robe prunes on August 17 and September 3 in one orchard and on September 4 in a second orchard. Results show that Robes consistently were lowest in total strength, but that little difference existed between Imperial and French. The results from the Yuba City orchard indicate a general increase in strength of about 10% from August 17 to September 3. It was also noted that shear strength at the cambium was about 60% of the total shear.

The comparative bark strengths for four species, Texas almond, Blenheim apricots, Red Haven peaches, and French prunes, were also measured — under "wet" and "dry" conditions. Almond, apricots, and peaches all had the same strength (270 psi), while French prunes were slightly lower (245 psi) in the dry plot. The bark strengths (both wet and dry) were about the same except for the Red Haven peach, which maintained about 55 psi greater strength in the dry plot than in the wet plot.

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TESTING PERMANENT FASTENERS

for shaker attachment to reduce limb injury in fruit and nut tree harvesting

P. A. ADRIAN · R. B. FRIDLEY · DAVID CHANEY

To reduce shaker-clamp injuries on fruit and nut trees as described in a companion article in this issue of *California Agriculture*, tests were made to check the feasibility of using permanently installed fasteners for shaker attachments. This has the advantage of transmitting the shaking force through the fastener to the structural wood rather than through the vulnerable bark and growing tissue.

Threaded rods

The project was initiated in 1962 when threaded rods were installed in trunks of a number of prune and peach trees early in the spring. Three-fourths-inch and 1-inch rods were placed in both clearance and undersize holes. First, the bolt hole was drilled completely through the trunk; then a spur drill was used to make a flat surface into the hard wood for a flat washer to bear against. For the shaker attachment, a trailer hitch ball was placed on one end and the shaking force was directed approximately in line with the rod.

By harvest time, a thin layer of callus had formed over the edge of many washers. This layer was not disturbed during shaking. The ¾-inch bolt had sufficient strength for all shaking forces, provided the attachment was no greater than 2 to 3 inches from the tree. It was also found that clearance holes were adequate. The only problem encountered was the collapse of very old trees which had decayed internally.

TABLE 1. MEASURED WITHDRAWAL RESISTANCE FOR LAG SCREWS AND NAILS INSTALLED AND TESTED IN GREEN ALMOND WOOD

Type of Fastener	Hole diameter (in)	Withdrawal resistance*	
		Yield Force (lbs)	Ultimate Force (lbs)
1/2" Lag screw	5/16	3250	3400
	3/8	3550	3950
	7/16	3350	3570
5/8" Lag screw	7/16	5450	5720
	1/2	5770	6250
	9/16	5200	5600
3/4" Lag screw	5/8	6000	6500
1/2" Screw nail	1/2	2500	2700
5/8" Screw nail	5/8	2800	3020
3/4" Screw nail	3/4	—	3450

* Results given are averages of two measurements except for 3/4-inch fasteners which are one measurement.

Laboratory tests

During these tests, considerable time was required for drilling holes and installing bolts, washers, and nuts. Therefore, in 1964 when the problem of longitudinal bark failure led to tests of fasteners in limbs, consideration was given to the use of different type fasteners which could be more easily installed. First, laboratory tests were conducted to determine the withdrawal resistance of lag screws and screw nails installed in pre-drilled holes to a depth of five times the bolt diameter. The screw nails were made by twisting square bar stock. Results are presented in table 1 and indicate that the greatest resistance was developed with lag screws in holes ⅛-inch undersize. Minimum hole-diameter for screw nails had to be approximately equal to the square stock size to install screws without splitting the wood.

Field tests

Field tests were also conducted to determine the sizes of the various fasteners required for shaking either limbs or trunks. The fasteners shown in photos were installed in optimum hole sizes as determined by the laboratory tests. Installations were made in limbs and trunks of both mature and young prune trees. All fasteners were made of mild steel and were positioned so that the shaking force would be directed approximately in line with the fastener.

Holes were drilled with an impact wrench, which was easier and faster than using the 1-inch drill used in the 1962 tests. Lag screws were the easiest to install. The screw nails were hard to drive, especially in limbs, because the limbs were not sufficiently rigid. Threaded rods in limbs resulted in enough wood being removed to weaken the limb.

All limb fasteners had or were fitted with an eye, and a shaker clamp was designed to attach to them. With screws and nails, the center of the eye was about 3 inches from the limb, and with the threaded rod the distance was about 5½ inches. The center of the ball on the trunk attachment was located about 7½ inches from the edge of the trunk.

Fastener alignment

A summary of the results is shown in table 2. With the exception of one screw nail, all fasteners were satisfactory on the young prune trees. However, on the mature trees, misalignments of 5 to 10 degrees resulted in bending ½- and ⅝-inch diameter lag screws and threaded rods. In addition, some screw nails were pulled out. This indicates that if misalignment of the shaker is no more than 5 degrees, the minimum diameter of mild steel fasteners required for use in limbs and trunks of mature trees would be ⅝ inch and ¾ inch, respectively. In addition to requiring accurate alignment, the force would have to be applied to the fastener at a point no more than 2 to 3 inches from the tree.

Removal of fruit was observed to be at least equivalent to removal obtained using conventional clamps.

Perpendicular force

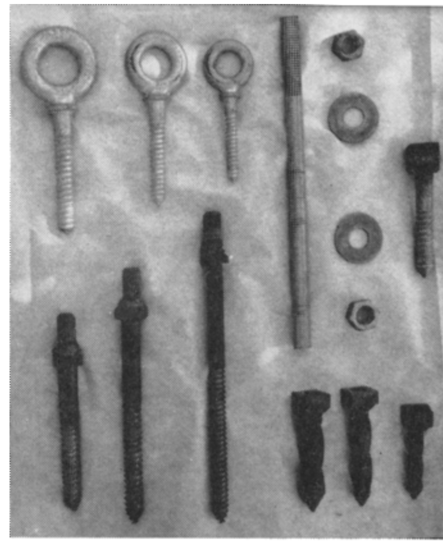
Since removal of fruit by trunk-shakers has been found to be improved by shaking in more than one direction, limited tests were conducted on mature almond trees to investigate the possibility of shaking perpendicular to the fasteners. The first tests were made on mild steel threaded rod, 1 inch in diameter, passing all the way through the trunk and extending out about 4 inches on either side. The trunk shaker was equipped with a set of V-shape grips to clamp on the ends of the rod.

TABLE 2. FIELD TESTS OF SHAKING IN LINE WITH FASTENERS PLACED IN TREE LIMBS AND TRUNKS

Type of fastener	Young trees: Number tested	Young trees: Problems encountered	Mature trees: Number tested	Mature trees: Problems encountered
LIMBS				
½" Lag screw	12	none	3	none
⅝" Lag screw	3	none	2	none
¾" Lag screw	—	—	2	none
½" Screw nail	3	none	2	1 pulled out
⅝" Screw nail	3	1 pulled out	2	1 pulled out
¾" Screw nail	—	—	1	gumming at nail
½" Threaded rod	—	—	7	4 bent*
⅝" Threaded rod	—	—	4	1 bent*
TRUNKS				
⅝" Lag screw	1	none	2	2 bent*
¾" Lag screw	2	none	2	1 loosened
¾" Screw nail	1	none	2	nail failed at weld
⅝" Threaded rod	—	—	2	1 bent*
¾" Threaded rod	2	none	2	none

*All bent fasteners occurred when shaker was misaligned about 5 to 10 degrees.

The mild steel rods did not have sufficient strength. Tests were then conducted on 1-inch diameter lag screws which were hand forged and heat treated to an ultimate strength of 150,000 psi (three times mild steel) and inserted into each end of a hole drilled through the trunk. Results of field tests on three trees showed satisfactory results, when the lag screws did not extend out of the tree more than 2 inches. When they extended more than 2 inches, the bearing strength of the wood was not sufficient to support the screws, and they became loose in the tree.



Types of fasteners tested.

Lag screws in limbs.

Threaded rod and trailer hitch ball.

Shaker clamp for attachment to eyes.