Structural failure profile: Monterey pine (*Pinus radiata*)

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EACH YEAR, THE STRUCTURAL FAILURE OF trees in urban and forested recreation areas results in personal injuries and property damage (Fig. 1). A key objective of a tree management program is to reduce the potential for failure to the extent possible. One important element of failure reduction strategies is to prevent or mitigate conditions that may lead to failure, such as pruning branches weakened by wood decay, cabling or bracing, and avoiding root damage.

All tree species do not fail in similar ways, however. Some are prone to fail as a result of weak architecture, such as codominant stems. Others have a greater propensity to fail because they develop large end-weights on branches that exceed the load tolerance of the wood. Knowing the particular failure patterns or traits of species can help tree managers identify key defects that may lead to failure.

By collecting detailed information following the failure of a tree, data can be compiled and then used to develop structural failure profiles for a species. Such a profile has been developed here for Monterey pine (*Pinus radiata*) using data from the California Tree Failure Report Program (CTFRP). Arborists and foresters can use this information to develop structural management strategies for Monterey pine. The development of this profile was commissioned by the Britton Fund of the Western Chapter of the International Society of Arboriculture.

Table 1.
General statistics for all failure types.

Variable	Mean
Age	59 years
Height	71 feet
DBH	32 inches
Crown spread	41 feet

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Figure 1. Property damage is not uncommon when large trees fail in urban areas. It is quite fortunate that this house was not damaged more severely when a nearby Monterey pine failed.

Monterey pine distribution

Monterey pine is native to the central coast of California and can be found in naturally-occurring stands in San Mateo, Santa Cruz, Monterey, and San Luis Obispo counties. Trees within this range are threatened by pitch canker, caused by the fungus *Fusarium circinatum*. It is also commonly found planted outside its native area as a landscape tree and for timber.

General statistics

There are a total of 534 reports in the database for Monterey pine, with 37% being branch failures (197), 36% root failures (191), and 27% trunk failures (146).

Most failures (86%) occurred on trees that were between 26 and 100 years old (Table 1). Reports came from 20 counties, but the majority (333 reports) are from San Francisco. Monterey pine failures occur more commonly

Figure 2. Failures along branches are common in Monterey pine...typically due to heavy end weights. Here, two branches have failed beyond the point of attachment.

in the winter months, with 52% of failures reported from November to February.

Most failed trees were found in a group (62.5%), in high use areas (40%), and in parks (52%). The most common defect for all failures was heavy lateral limbs, observed in 29% of reports, followed by dense crowns (11%) and leaning trunk (10%).

A. BRANCH FAILURE

Branch failure was reported in 197 cases, or 37% of total reports.

Branch failure location

The majority of branches failed at some distance along their length (70%) (Fig. 2). Failures along the branch occurred mostly within 6 feet (35%) of the attachment, and mostly in the 9-12 inch diameter range (19%). The majority of trees with branch failures were between 26 and 50 years old (35%), followed closely by those aged 76 to 100 (33%) and 51 to 75 (29%).

The main structural defects observed in trees with failed branches are heavy lateral limbs, multiple trunks, and dense crowns, observed in 72%, 10%, and 5% of cases (Table 2).

Decay and branch failures

Decay was reported in 11% of the branch failure cases. The cross-sectional area of decay was given in 20 reports, where 65% had less than 25% of the area decayed (Table 3).

Wind and branch failures

Most branch failures (51%) occurred under moderate wind conditions (5-25 mph), followed by failures in low wind (under 5 mph). (Table 4).

Precipitation and branch failures

The majority of branch failures occur during rainfall events (64%).

B. TRUNK FAILURE

Trunk failures occurred in 146 cases, or 27% of reported failures. Most occurred at a distance above ground level (77%), while 23% occurred at ground level (51%). Trunk

Table 2. Defects reported associated with branch failures.

Defect	Frequency
Heavy lateral limbs	72%
Multiple branches or codominant stems	10%
Dense crown	5%

Table 3. Cross-sectional area of branch with decay and failure occurrence.

Cross-sectional area with decay	Frequency
< 25%	65%
26-50%	30%
51-75%	0%
> 76%	6%

Table 4. Wind speed and branch failure.

Wind speed	Frequency of occurrence
Low wind (<5 mph)	32%
Moderate wind (5-25 mph)	51%
High wind (>25 mph)	17%

diameter at the point of failure ranged from 5 to 60 inches, with the majority (51%) between 13 and 24 inches in diameter. The primary defect associated with trunk failure is dense crowns (18%). Leaning trunks, dead portions of the tree and multiple trunks were also associated with failure (in 13%, 12%, and 11% of cases, respectively). (Table 5)

Decay and trunk failure

Decay was reported in 51% of trunk failures (Fig. 3). The cross-sectional area of decay was reported in 59 cases, with 62% of trees with less than 50% cross-sectional area decayed (Table 6).

Wind and trunk failures

Trunk failures most commonly occurred during high wind conditions exceeding 25 mph, followed by failure at moderate wind (31%) and low wind (27%). (Table 7).

Table 5. Defects reported associated with trunk failures.

Defect	Frequency
Dense crowns	18%
Leaning trunk	13%
Failed portion dead	12%
Multiple trunks/codominant stems	11%

Table 6. Cross-sectional area of trunk with decay and failure occurrence.

Cross-sectional area with decay	Frequency
< 25%	32%
26-50%	30%
51-75%	24%
> 76%	14%

Figure 3. Although decay is reported in many cases of trunk failure in Monterey pine, the wood appeared largely sound in this case.

Table 7. Wind speed and trunk failure.

Wind speed	Frequency of occurrence
Low wind (<5 mph)	27%
Moderate wind (5-25 mph)	31%
High wind (>25 mph)	42%

Figure 4. Root failure is the second most common type of failure for Monterey pine. Here, a Monterey pine on a sandy slope with an unbalanced crown uprooted very close to apartment buildings.

Precipitation and trunk failures

The majority (52%) of trunk failures occurred during dry conditions.

C. ROOT FAILURE

Root failure is the second most common failure type, with 188 reports (35% of total) (Fig. 4). Trees experiencing root failure ranged from 4-100 years old, with the majority (39%) aged 26-50.

Table 8. Defects reported associated with root failures.

Defect	Frequency
Leaning trunk	18%
Uneven - one side	13%
Dense crown	13%

Figure 5. Decay is not a contributing factor in the majority of root failures in Monterey pine. No decay was evident in the roots of this Monterey pine.

Defects and root failures

The most common defects were leaning trunks (19%), uneven canopies with most of the weight to one side (14%), and dense crowns (14%, Table 8). No defects were observed in 13% of cases.

Decay and root failures

Root decay was observed in 27% of failures (Fig. 5). The cross-sectional area of decay was reported in 44 cases, with the majority (43%) decayed between 26-50% of the area (Table 9).

Wind and root failures

The majority (46%) of root failures occurred during high wind conditions, while 38% and 15% of failures occurred under moderate and low wind speeds, respectively (Table 10).

Precipitation and root failures

Most of the trees with root failures (73%) were reported to have failed during rainfall events.

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Table 9. Cross-sectional area of root with decay and failure occurrence.

Cross-sectional area with decay	Frequency
< 25%	38%
26-50%	43%
51-75%	11%
> 76%	7%

Table10. Wind speed and root failure.

Wind speed	Frequency of occurrence
Low wind (<5 mph)	15%
Moderate wind (5-25 mph)	38%
High wind (>25 mph)	46%

Summary of key findings:

- Branch and root failures comprise 72% of Monterey pine failure reports (37% and 35%, respectively).
- Most branch failures (51%) occurred under moderate wind conditions (5 and 25 mph), followed by failures in low and high wind (32% and 17%, respectively). Trunk and root failures were both more common at high wind speeds (42% and 46%, respectively).
- The majority of branch (64%) and root (73%) failures occurred when there was some form of precipitation, while trunk (52%) failures generally occurred during dry conditions.
- Decay was associated with 11%, 51%, and 27% of branch, trunk, and root failures, respectively.
- The majority of the decayed portion of the cross-sectional area at the point of failure was under 25% for branch failures (65%) and under 50% for both trunk (62%) and root (81%) failures.
- Branch failures were more common along the length of the branch than at the attachment (70% of cases).
- Heavy lateral limbs are the primary defect associated with branch failures, occurring in 72% of cases, followed by multiple branches and dense crown.
- Trunk failures were more common above ground level (77%). Most failed trunks were between 13 to 24 inches in diameter at the point of failure.
- The most common defects associated with trunk failures were dense crowns, leaning trunk, failed portion dead, and multiple trunks.
- The most common defects associated with root failures are leaning trunk, unbalanced crown, and dense crowns.