Alaska Department of Transportation & Public Facilities
Alaska University Transportation Center

The Response of Pile-Guided Floats Subjected to Dynamic Loading
Volume II Annex

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August 2014

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Pile-Guided floats can be a desirable alternative to stationary berthing structures. Both floats and guide piles are subjected to dynamic forces such as wind generated waves and impacts from vessels. This project developed a rational basis for estimating the dynamic response of pile-guided floating structures. The Dynamic Analysis Method (DAM) was used to model the response of the system. MATLAB was used to compute the analytic and numerical values obtained from the dynamic models. ANSYS AQWA was used to validate the dynamic analysis models used in this study.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Annex A

Navy Report TM-6044-OCN_Dynamic_Ferry_Berthing

Naval Facilities Engineering Command

ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

TECHNICAL MEMORANDUM
TM-6044-OCN

Dynamic Modeling of Ferry Berthing

by

William N. Seelig, P.E.
Gerritt Lang, E.I.T.

18 June 2010

Prepared for:

University of Alaska Fairbanks

EXECUTIVE SUMMARY

University of Alaska Fairbanks Department of Civil and Environmental Engineering is developing tools for analyzing ferry berthing for cases of high tidal range and potentially deep water. Therefore, they tasked NAVFAC Engineering Service Center to assist with dynamic modeling of these systems due to the Navy's expertise in this area. Figure A shows a sample numerical model of a complete berthing system.

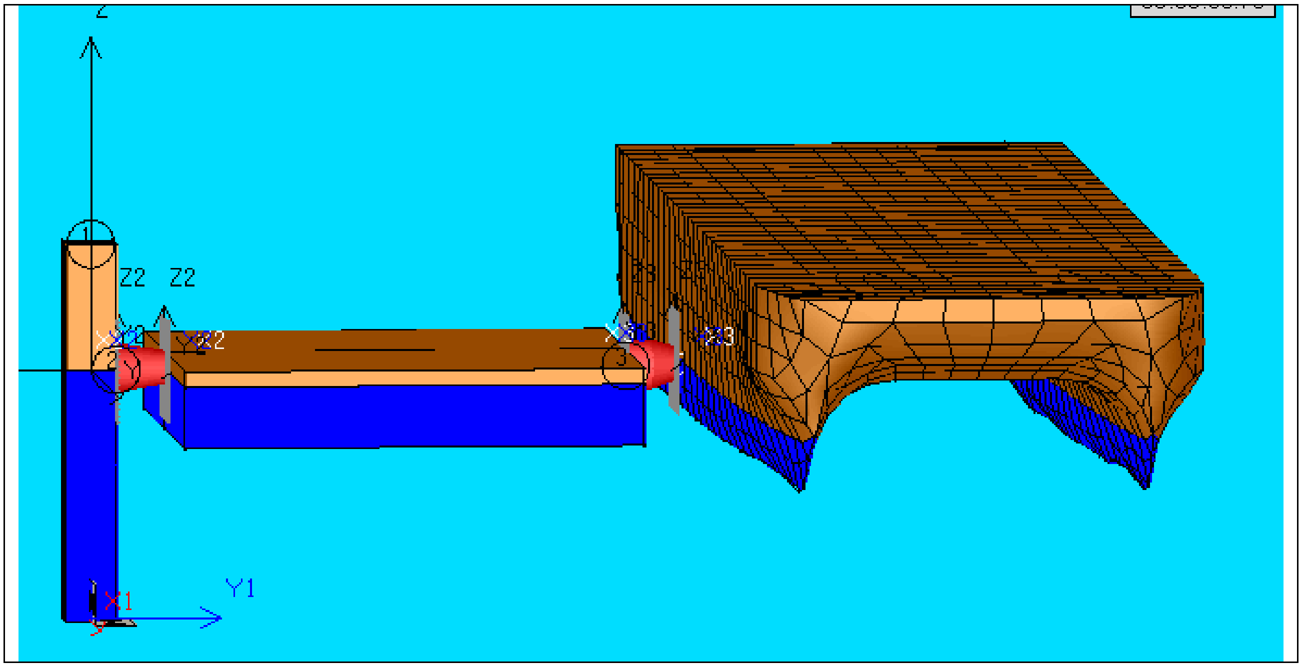

Figure A. Sample Model of Ferry Berthing
(FVF Berthing in Sway to a Concrete Platform)

A wide variety of dynamic ferry berthing simulations were conducted using the ANSYS AQWA v12.0 suite of software and results are presented in this report in a systematic manner. The goal is to use these results to aid in developing improved ferry berthing design and analysis methods.

Dynamic Modeling of Ferry Berthing

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Gerritt Lang, E.I.T.

1.0 INTRODUCTION / PURPOSE

University of Alaska Fairbanks Department of Civil and Environmental Engineering is developing tools for analyzing ferry berthing for cases of high tidal range and potentially deep water. Therefore, they tasked NAVFAC Engineering Service Center to assist with dynamic modeling of these systems due to the Navy's expertise in this area. In this report a wide variety of dynamic ferry berthings will be conducted using the ANSYS AQWA suite of software and results are presented in a systematic manner. The goal is to use these results to help calibrate design and analysis methods.

2.0 BERTHING

When a vessel comes into a facility that vessel usually has some velocity and associated kinetic energy / momentum. Therefore, the berthing facility must be designed to dissipate the kinetic energy in a manner that keeps the vessel, facility and personnel safe at all times.

The berthing process is somewhat complicated in that it is highly dynamic and involves various masses, inertia, damping and system stiffness. The U.S. Navy is highly interested in keeping its vessels safe during berthing, so a major study is underway for the Navy. The U.S. Navy work includes a combination of physical modeling conducted at the U.S. Naval Academy and extensive numerical modeling being conducted by NAVFAC Engineering Service Center. Figure 1 shows a sample submarine berthing scale model test.

In this report many of the lessons learned in the Navy work is applied to the unique cases where the tide range may be high and the water relatively deep.

Figure 1. Test Setup for U.S. Navy Physical Modeling of Submarine Berthing

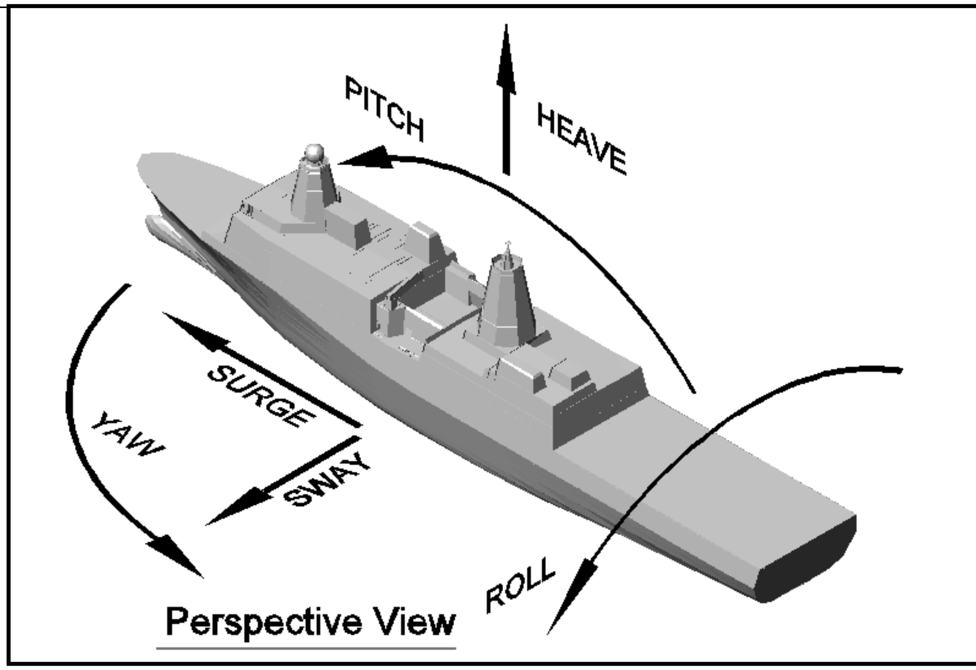
Table 1 summarizes the notation used in this report.

Note that in this study each vessel or object is treated as a six degree-of-freedom structure and a local right-handed coordinate system is assigned to each object, as summarized in Figure 2. A right-handed global coordinate system is then assigned to each case analyzed. In the global system the still water surface is taken as Z = 0 with Z+ in the upward direction.

Table 1. Notation Used

Variable	***Description***
B	Vessel width; for ships use waterline width; for subs use total width
Cb	Vessel block coefficient; Cb= submerged volume/(B*L*T)
d	Water depth
Cm	Added mass coefficient Cm=1+Ma/M
Cm0	Added mass coefficient coefficient for T/d=0*
Cm1	Added mass coefficient coefficient for T/d=1*
Cm’	Berthing sway added mass coefficient Cm’=1+Ma’/m
E	Total kinetic energy of a vessel moving
F	Force
g	Acceleration due to gravity
k	Stiffness
KE	Kinetic energy = (1/2)*Cm*M*V^2
L	Vessel length at waterline
M or Mship	In-air mass of object or ship = weight/g
Ma	Added mass of water*
Ma’	Berthing added mass of water
T	Mean ship draft
V	Initial incoming vessel speed when berthing
W	Weight of vessel = mass * g

* due to oscillating motion for a long-period sway oscillation



X – surge Y – sway Z – heave RX – roll RY – pitch RZ - yaw

Figure 2. Vessel Degrees of Freedom

Several very important lessons have recently been learned in the U.S. Navy work underway and are applied to the Alaska modeling:

LESSON 1 – ADDED MASS. The in-coming kinetic energy is very important in berthing dynamics, where the kinetic energy is given by:

$$KE = (1/2) * mass * V^2 \qquad \text{Eq (1)}$$

The Navy work shows that the mass in Eq (1) includes the mass of the ship but also the mass of entrained water moving with the ferry. It turns out the mass of entrained water can be several times larger that the mass of the ship in U.S. Navy cases, so:

$$mass = Cm * M \qquad \text{Eq (2)}$$

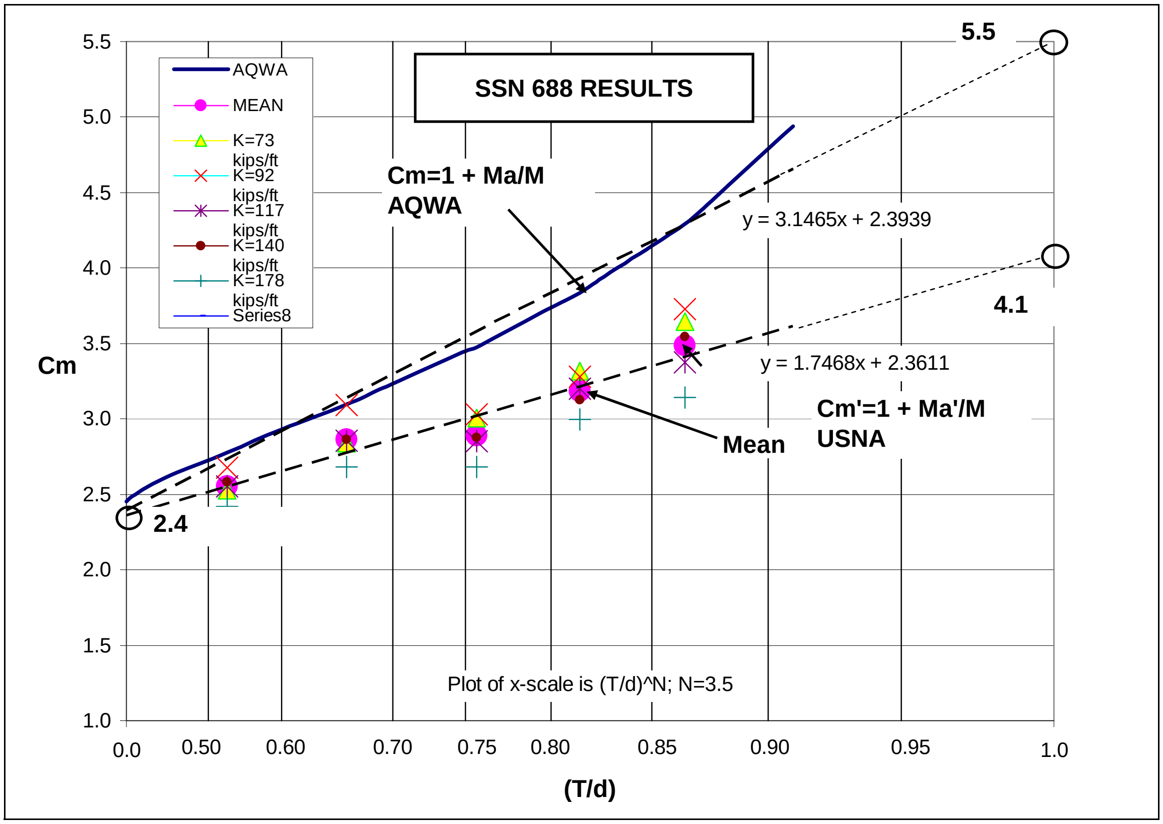
Where M is the in-air mass of a ship or object and Cm is the added mass coefficient (i.e. Cm = 1 + Ma/M: where Ma is the added mass of water entrained with the ship).

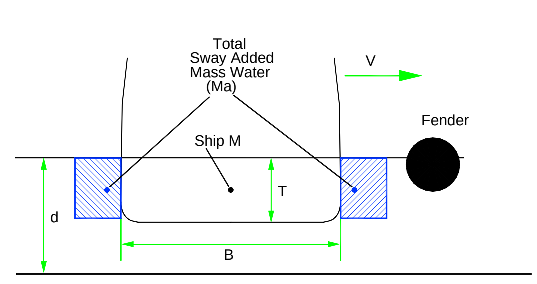
Fortunately the U.S. Navy work shows that the mass of entrained water can be reliability calculated by the ANSYS diffraction analysis, as shown in Figure 3 (upper curve). If the water is relatively deep, say the ship draft to water depth ratio (T/d)<0.33, then the ANSYS AQWA diffraction analysis results for low frequency motion can be used directly in Eq (1). Relatively deep water (i.e. good under-keel clearance) is likely the typical case in Alaska.

Fortunately the U.S. Naval Academy physical test results (Figure 3, lower curve) show that if the water is shallow then the ANSYS AQWA diffraction results can be adjusted using Figure 3 to match physical reality.

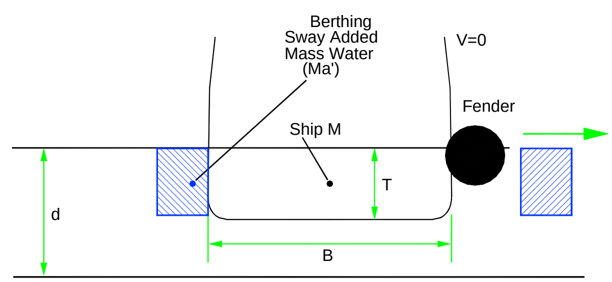
LESSON 2 – STIFFNESS EFFECTS ON ADDED MASS. In the U.S. Navy tests five values of effective structure/fender stiffness were modeled (five symbols in Figure 3 lower curve). It was found that structure/fender effective stiffness has practically no effect on the in-coming added mass of water. This helps simplify the number of cases that need to be analyzed for the Alaska ferry berthing modeling.

LESSON 3 – NUMERICAL MODELING GIVES GOOD RESULTS. Comparison of the U.S. Navy physical model test results with numerical modeling shows that the ANSYS AQWA is a good tool for simulating berthing. The numerical model is used directly for deep water (i.e. T/d < 0.33, which is the typical Alaska case) or the added masses are adjusted somewhat for the case of shallow water berthing (i.e. T/d > 0.33). It turns out in shallow water that not all of the added mass of water entrained with the moving ship needs to be stopped by the berthing facility. In shallow water some of the initially entrained water keeps on moving. The Figure 3 upper curve shows the total amount of water initially entrained with the moving ship and Figure 3 lower curve shows the amount of water that needs to be effectively stopped by the berthing system.





Total Initial Entrained Mass of Water



Vessel Berthing – In Shallow Water A Portion of the Water Keeps on Moving and Does Not Need to be Stopped by the Berthing System

Figure 3. Sway Added Mass Coefficients for SSN 688 (244 Tests Conducted at U.S. Naval Academy, July 2009)

LESSON 4 – KINETIC ENERGY IS KEY.

Each of the U.S. Naval Academy data points (shown in the lower curve of Figure 3) actually represents a large number of tests. Each test series consisted of first berthing at a low speed. The test was then repeated at higher and higher berthing velocities. In all cases it was found that the in-coming kinetic energy is a good measure for determining the peak berthing load. Note that it is important to use both the ship mass and added mass of water to compute kinetic energy.

These physical model test results show that not very many ship velocity cases need to be made to understand berthing behavior.

3.0 ALASKA FERRY BERTHING SYSTEM

A representative Alaska ferry berthing system consists of the key components, as summarized in Table 2.

In the ANSYS AQWA modeling both the ferry and platform are modeled as diffraction structures. This is because both these systems are floating and make waves when they move. The pile system is modeled as a Morrison structure because it does not make much of a wave when the pile moves (i.e. the piles do not move very much and are relatively small).

Table 2. Alaska Ferry Berthing System Components

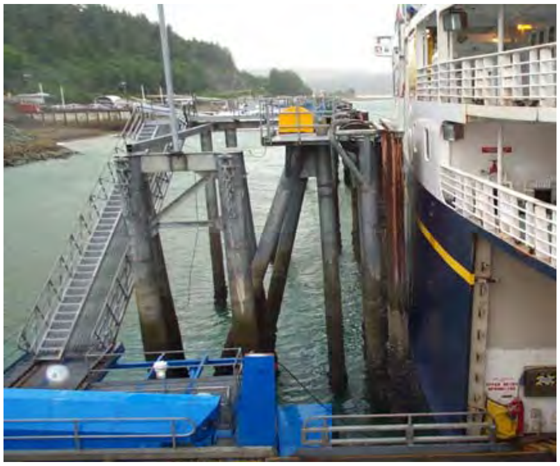
(a) Ferry

Notes	***Example***
The incoming vessel has a given geometry, the incoming velocity is specified and there is an entrained added mass of water moving with the vessel. The ANSYS suite of AQWA software is used to model the vessel geometry as a six-degree-of-freedom floating structure and the software is used compute added mass six-by-six matrices as a function of direction and frequency for the ship.	

(b) Platform / Fender

Notes	***Example***
The platform is a floating structure that moves up and down with the tide and which the ferry berths to. It also serves as a transfer platform. The ANSYS suite of AQWA software is used to model the platform as a six-degree-of-freedom floating structure and the software is used compute added mass six-by-six matrices as a function of direction and frequency for the platform. Various fender stiffness values are considered as specified.	

(c) Pile System

Notes	***Example***
The pile system holds the receiving platform in place and provides for the platform to move up and down with the tide. The pile system is modeled as a six-degree-of-freedom Morrison object and stiffness/mechanical damping are specified.	

4.0 DYNAMIC MODELING OF BERTHING

AQWA numerical dynamic models are built of the key components (ferry, float and pile system). These components are combined and dynamic simulations of ferry berthing conducted. Calculations are performed in the time domain to capture key features. A very short time step is used to record a complete set of data. Key parameters are systematically varied and the peak load predicted for each simulation is recorded. Note that SI units are used in the numerical models. Also, in this report "weight" means the force that an in-air object would exert on the earth at sea level, while "mass" means mass (i.e. weight/g; where g is the acceleration due to gravity).

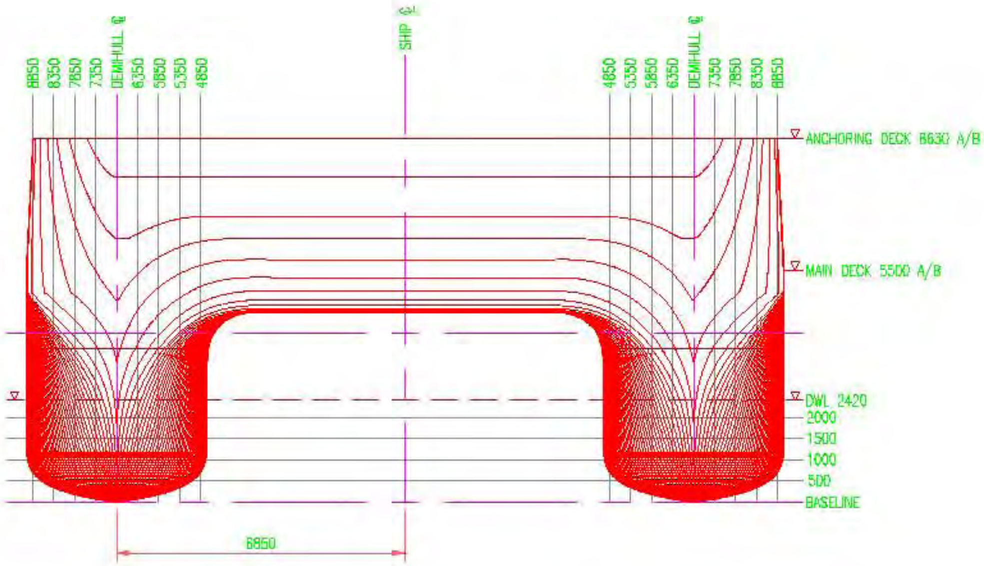
4.1 FERRY MODELS

AQWA six degree-of-freedom models are developed for the following vessels:

4.1.1 FAST VEHICLE FERRY (FVF)

These are high speed catamarans (Figure 4). Figure 5 shows an AQWA model of FVF hull formed using as-built ferry data from the keel to a point 8.63m above the baseline. The draft of these boats is 2.42m and vertical center of gravity (VCG) is 6.38m, which are for the “FULL LOAD Case 1” from the spreadsheet “AMH FVF FREEBOARD DATA, Updated to NG408-910-02 Issue 4”.

The lower portion of Figure 5 shows the AQWA LINE calculated surge-surge added mass of water and surge-surge radiation damping as a function of frequency. The show for a highly streamlined catamaran there is hardly any added mass in the surge direction and very little damping. This suggests in catamaran berthing calculations in surge only using the ship mass will likely give good results, which simplifies calculations for this type of situation.



(from CHENEHG issue2-as built)

Figure 4. Fast Vehicle Ferry

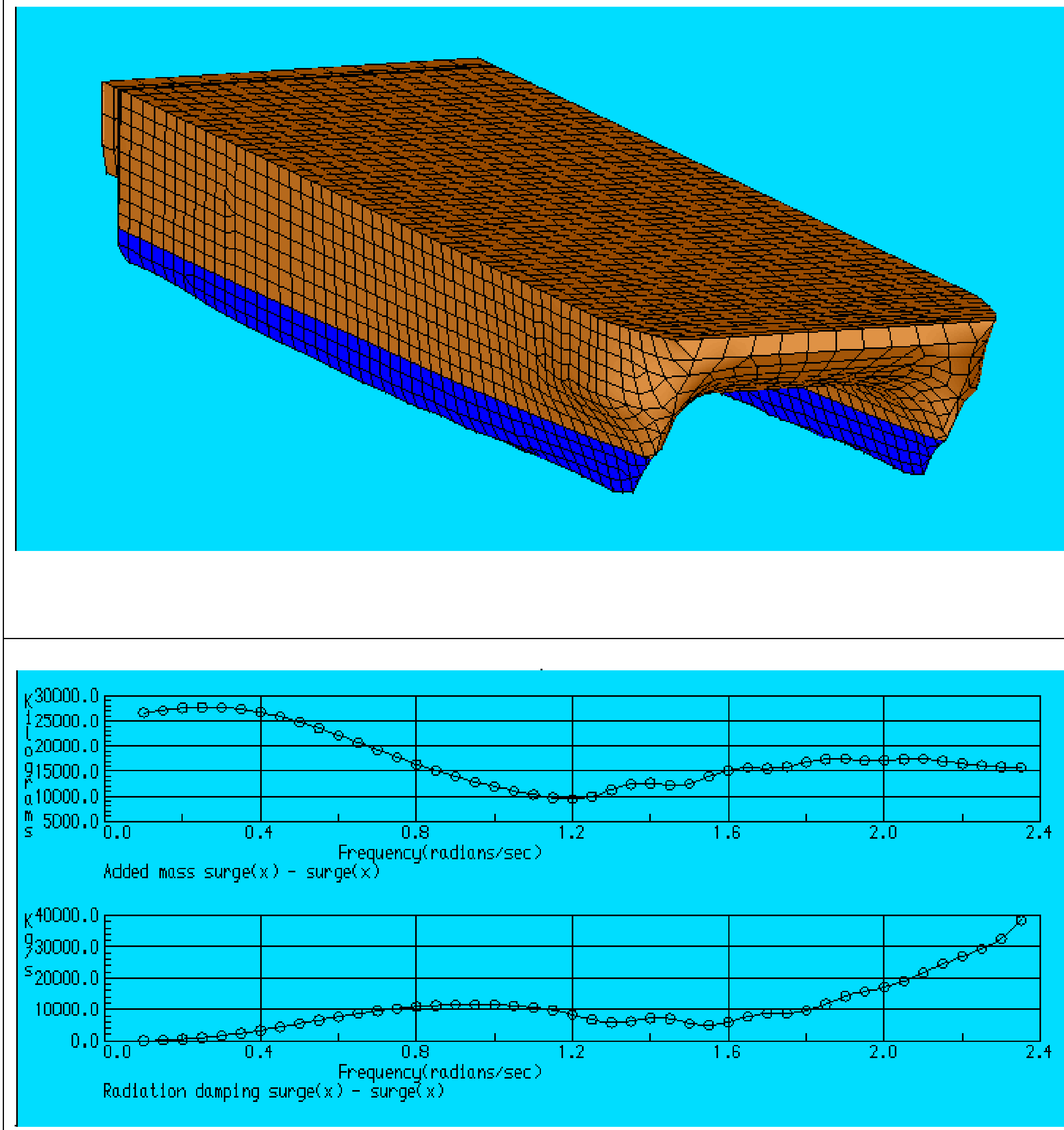
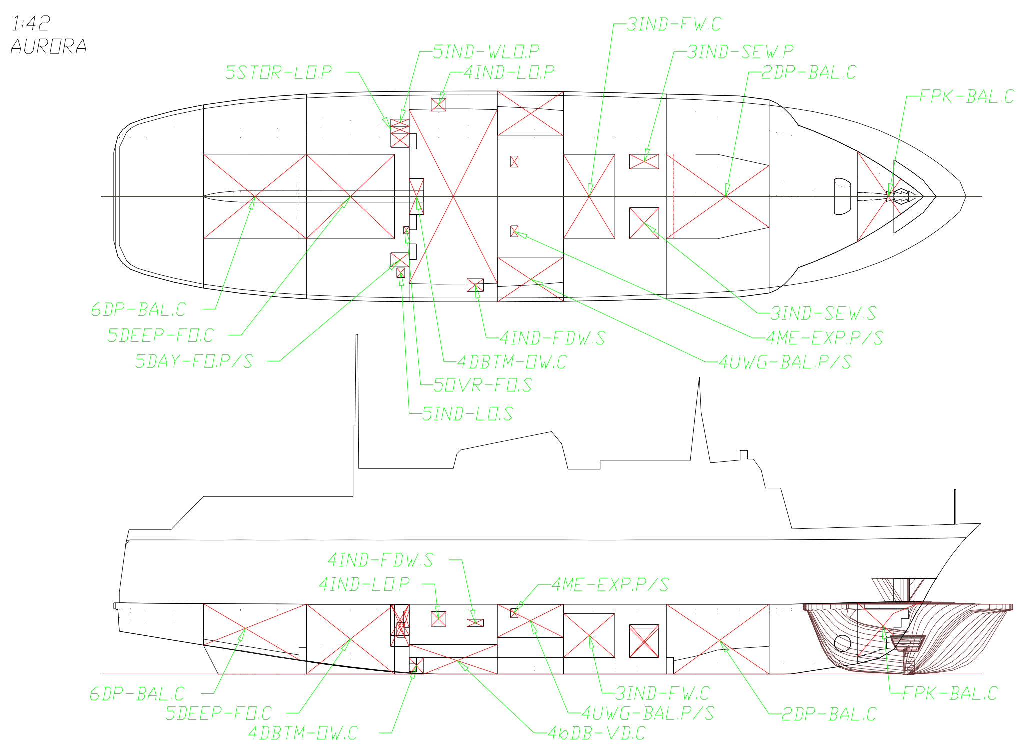


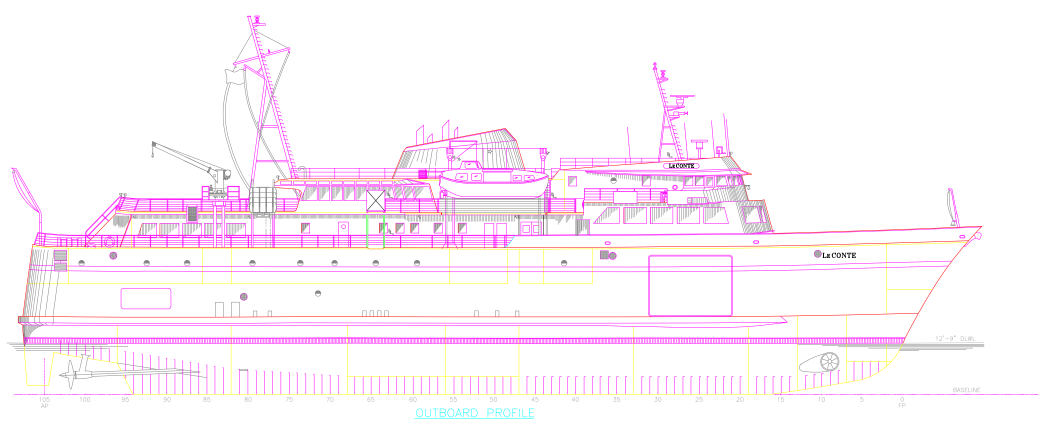
Figure 5. AQWA Hull Model of a Fast Vehicle Ferry and Sample Calculated Hydrodynamic Parameters

4.1.2 M/V AURORA AND M/V LECONTE

These are two vessels of the same class (Figure 6).

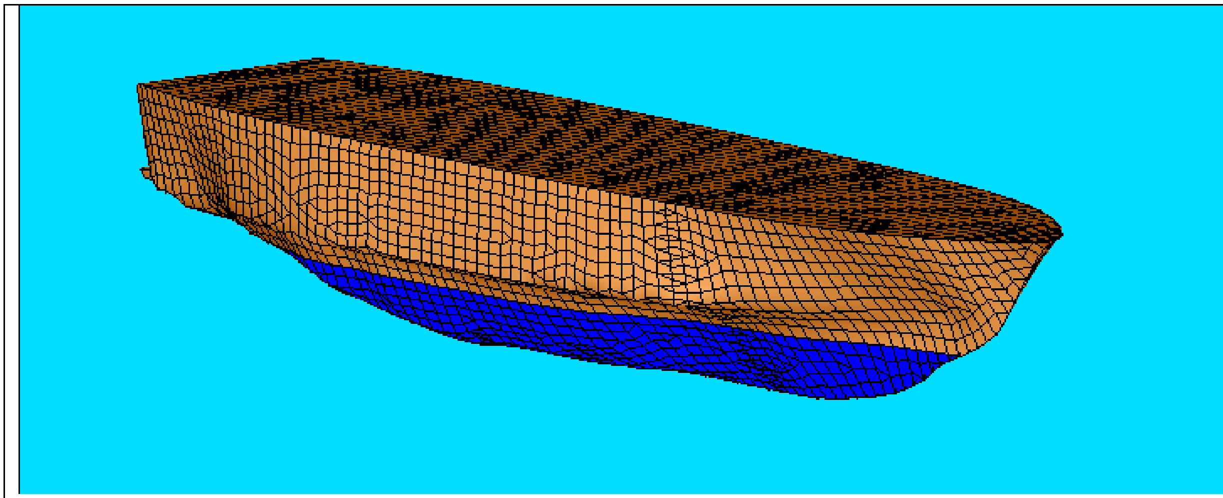


Length 210’, Width 55’, Draft 12’9” (AUR-ID.dwg)

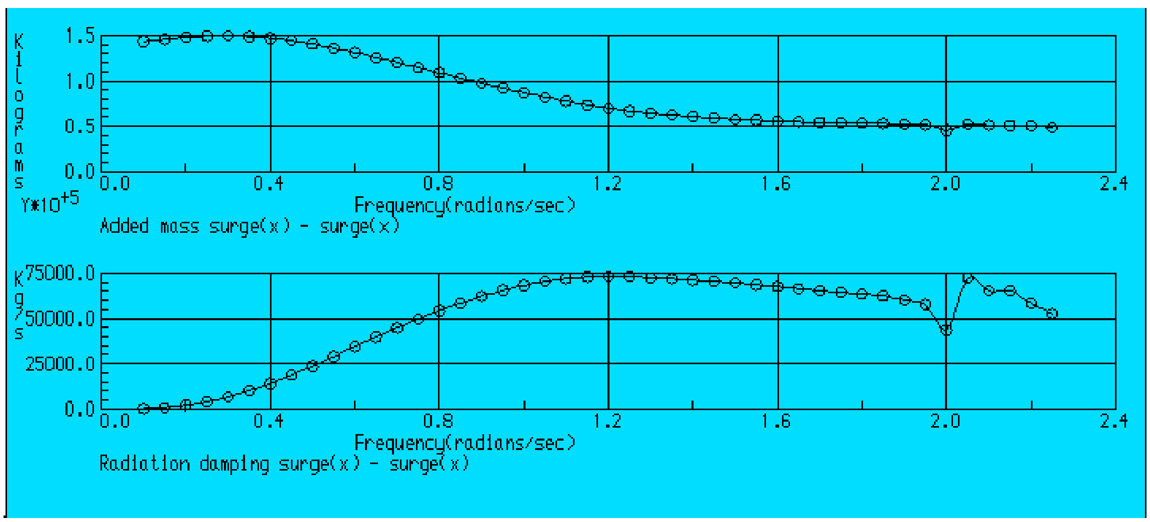


(LEC PROFILE.dwg)

Figure 6. M/V AURORA Class



AQWA MODEL from Baseline to 11.1m above baseline



Surge-Surge Added Mass and Radiation Damping

Figure 7. AQWA Hull Model of M/V AURORA Class and Sample Calculated Hydrodynamic Parameters

4.1.3 M/V KENNICOTT

This is a mono-hull class of ferry with a bulbous bow (Figure 8). We do not have detailed lines or tables-of-offset for this vessel. However, we do have the shape of the hull from the side, the location the hull cuts the waterline in plan view and the top of the hull in plan view (Figure 8). From this information, ship photographs and general knowledge of naval architecture we can estimate the hull shape, as shown in Figure 9.

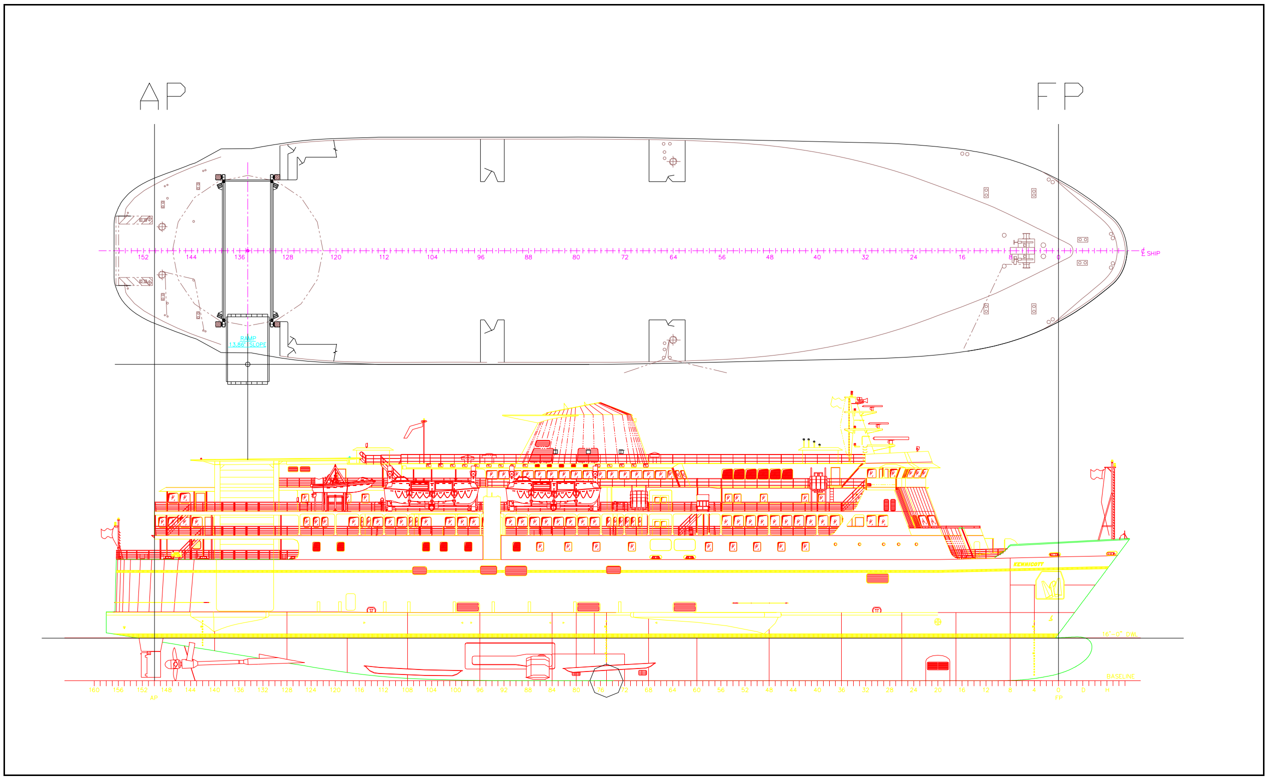
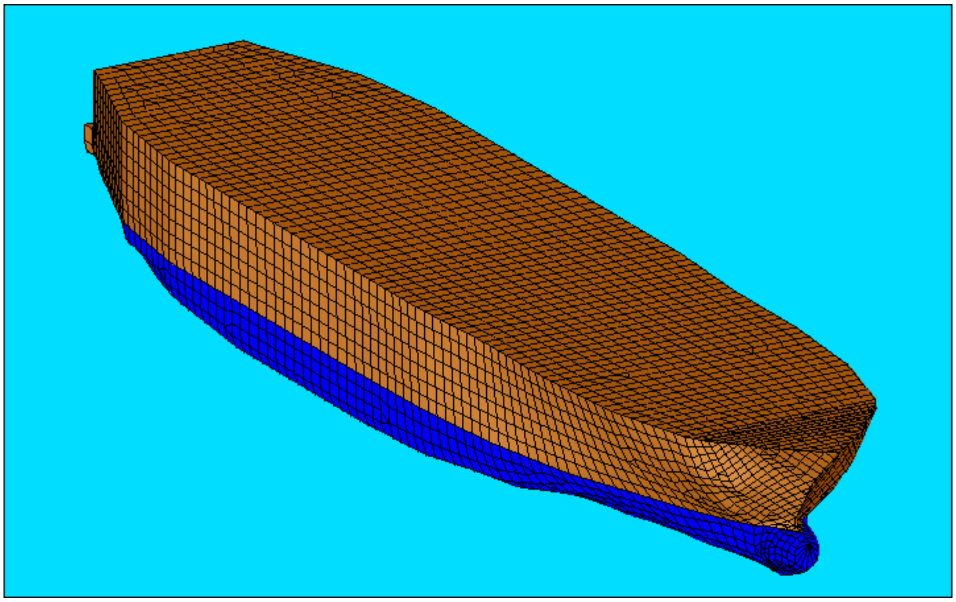
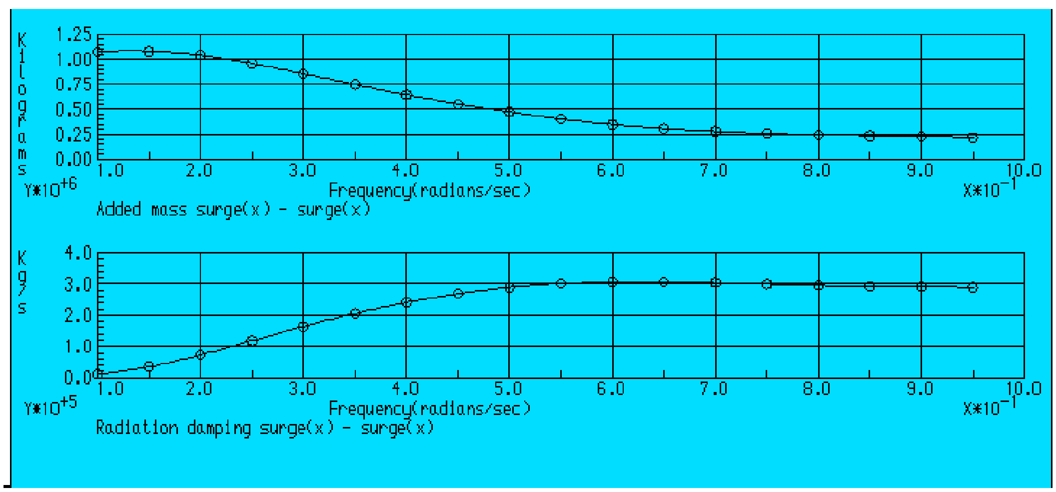


Figure 8. M/V KENNICOTT CLASS



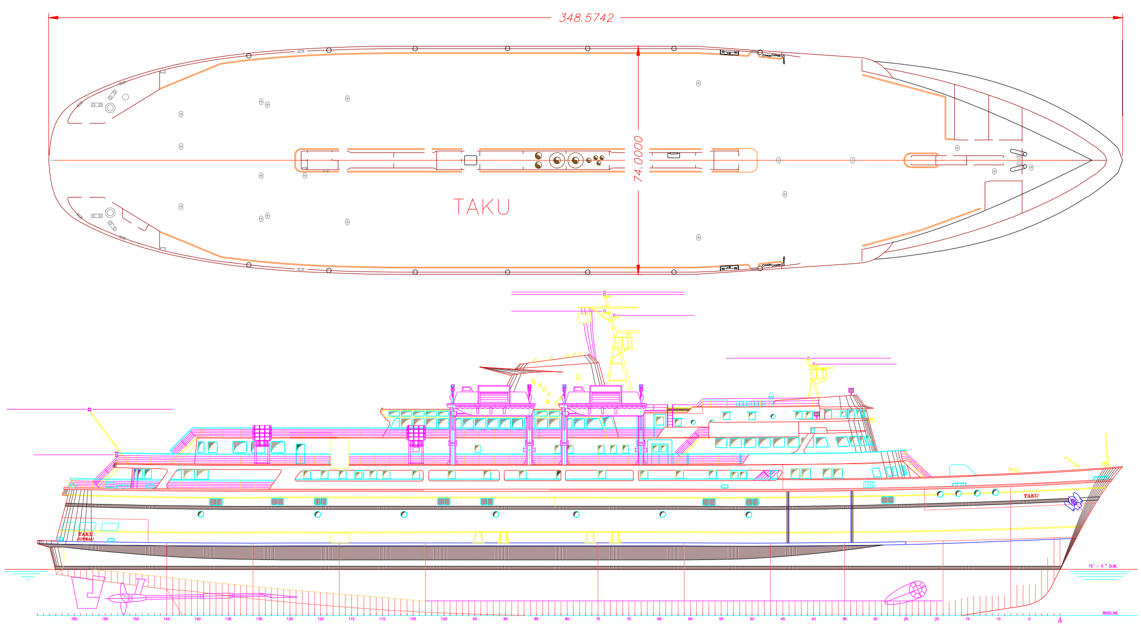


Surge-Surge Added Mass and Radiation Damping

Figure 9. Approximate AQWA Hull Model of M/V KENNICOTT Class and Sample Calculated Hydrodynamic Parameters

4.1.4 M/V TAKU

This is a mono-hull without a bulbous bow (Figure 10). We do not have a lines drawing or table of offsets for this vessel. However, inspection shows that this ship is very similar in shape to M/V AURORA, except with somewhat different dimensions. Therefore, the ratios of key dimensions (Figure 10, lower) are used to take the M/V AURORA AQWA model and use it to develop an AQWA model of M/V TAKU (Figure 11).



		DIMENSION (m)		Ratio
PARAMETER	***AXIS***	***M/V TAKU***	***M/V AURORA***	***TAKU/AURORA***
LENGTH	X	106.245	64.000	1.660
WIDTH	Y	22.555	16.764	1.345
DRAFT	Z	4.572	3.886	1.177

Figure 10. M/V TAKU CLASS

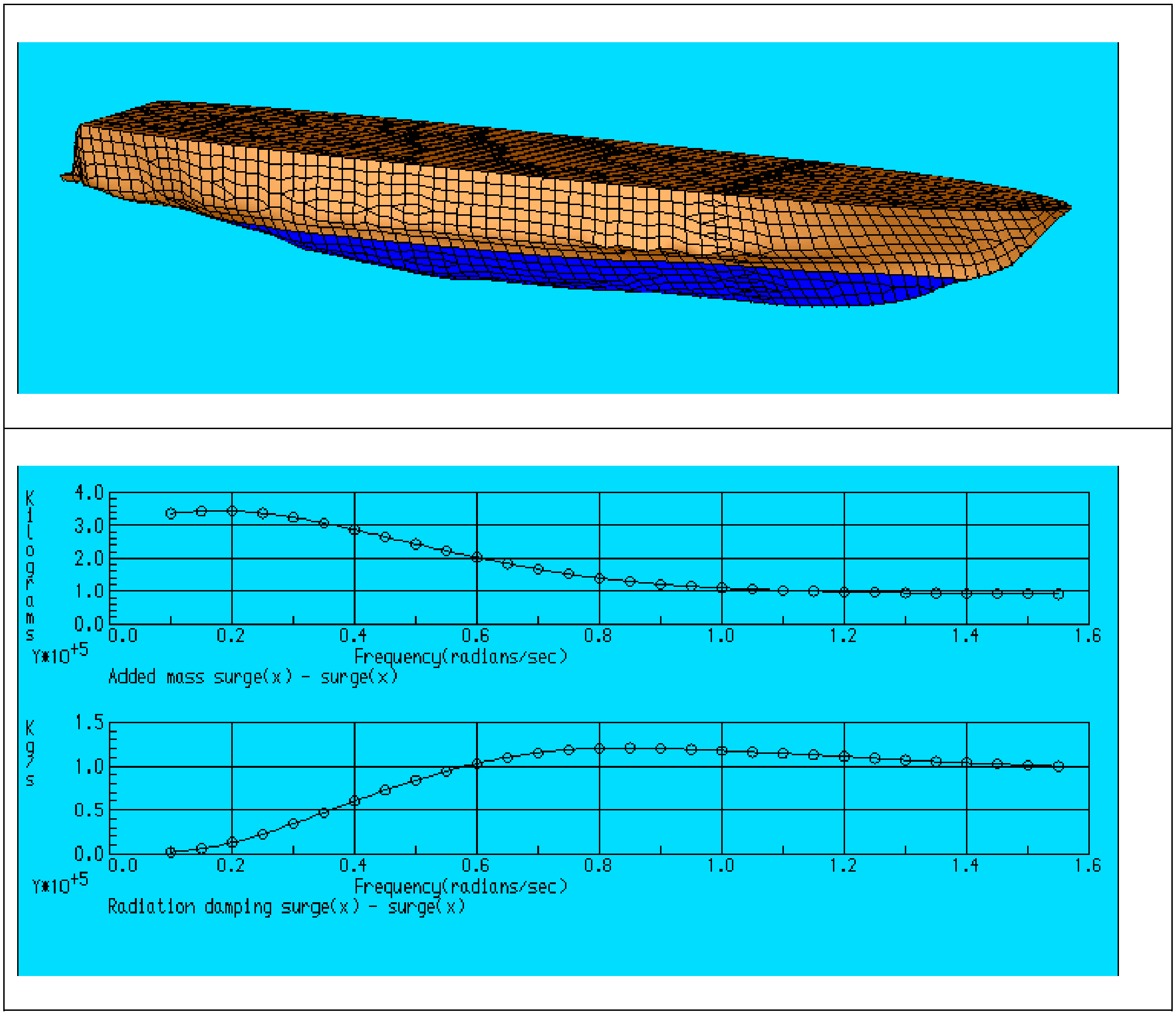


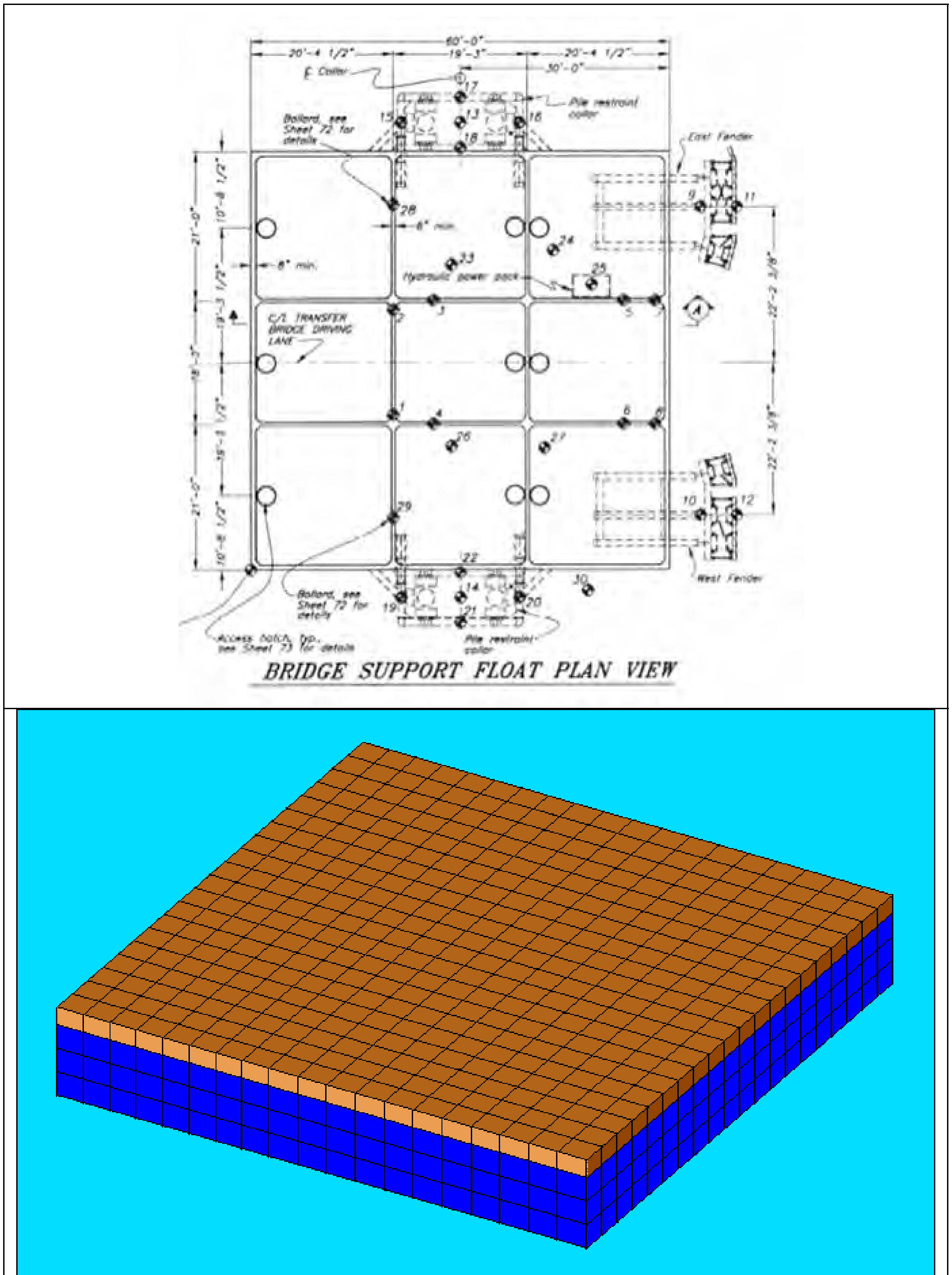
Figure 11. AQWA Modes of M/V TAKU Class Hull (Formed by scaling M/V AURORA)

4.2 PLATFORM / FENDER MODELS

An AQWA six degree-of-freedom models of a concrete float 60' x 60' x 10' with a draft of 8' is first developed (18.288m x 18.288m x 3.048m with a draft of 2.438m). This is float model "F1" (Figure 12). Based on the displacement of the float the float weight (including ballast and auxiliary equipment) is found to have a weight of 1,841.8 kips and a mass of 8.354E5 kg. The float is assumed to have vertical located at mid-height and associated moments of inertia of the float are calculated and input to the AQWA file. Also note that the float is wisely compartmented (Figure x upper). Therefore, sloshing of ballast water in floats is not considered in the AQWA models. Note that a relatively small panel size of 1m is used in the AQWA model so that potentially high frequency transient events can be captured.

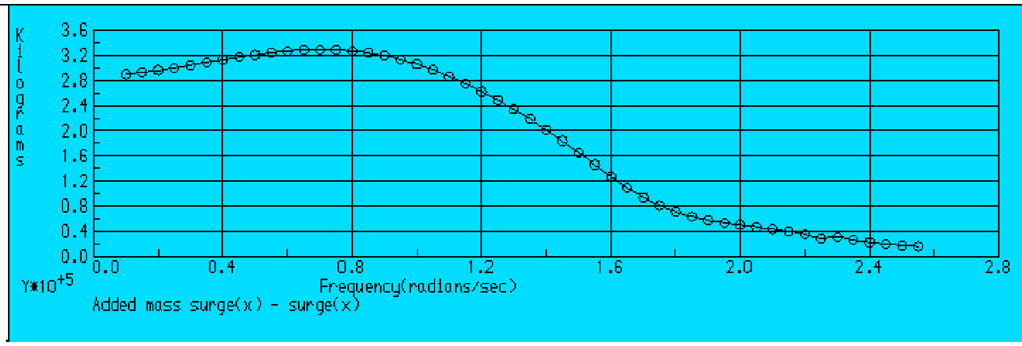
The AQWA LINE software is used to perform a diffraction analysis on platform F1 model. Results of the diffraction analysis include six-by-six matrices as a function of frequency and direction for a massive number of parameters, such as added mass, damping, etc. Figure 13, for example, shows results for some parameters as a function of frequency for one diagonal cell ('surge-surge') in the six-by-six matrices.

Additional platform models, if any are required, will be developed later in appendices.

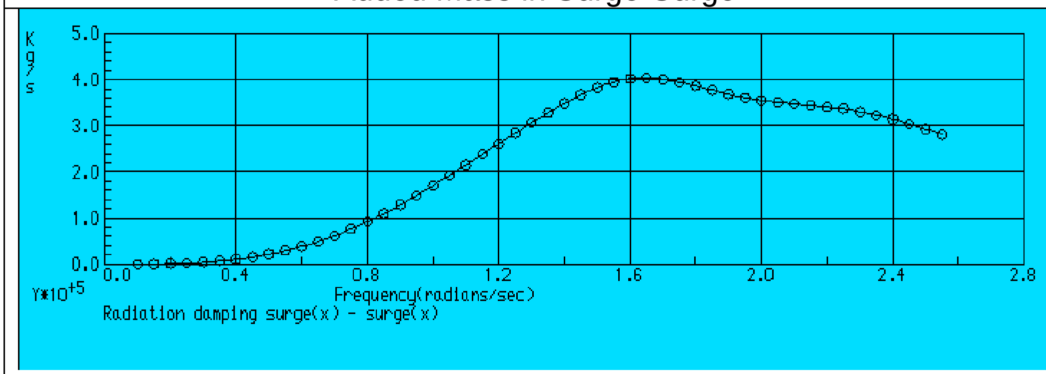


AQWA Model – Perspective View

Figure 12. Concrete Float and AQWA Model of Ketchikan Berth III (Float Model F1)



Added Mass in Surge-Surge



Radiation Damping in Surge-Surge

Figure 13. Sample AQWA Diffraction Results in Surge for Concrete Float F1

4.3 PILE MODELS

The pile systems are modeled as lumping all the various structural components into one effective system. For example, assume a system can be modeled as a single pile with effective dimensions of 2m x 2m, mean density of 2300 kg/m^3 and a length longer than the water depth. For example, the water depth is taken as 10m (33 ft) and pile length as 15m (49 ft) for pile model P1 (Figure 14).

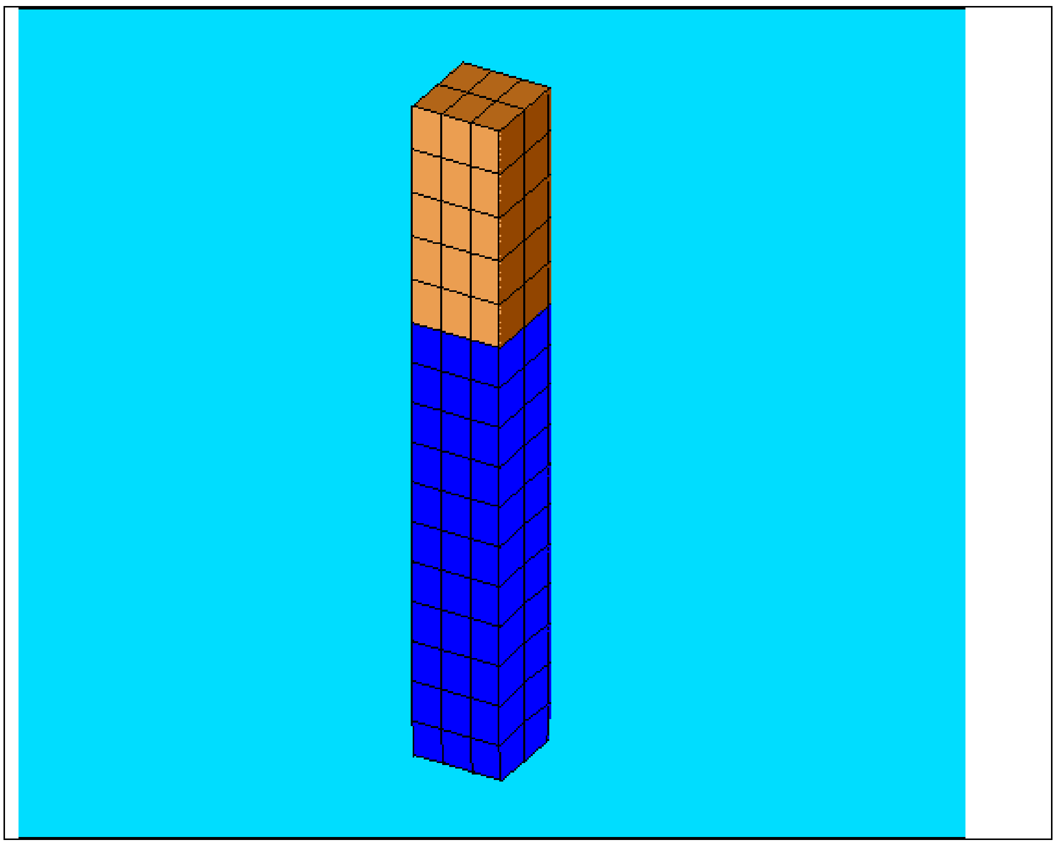


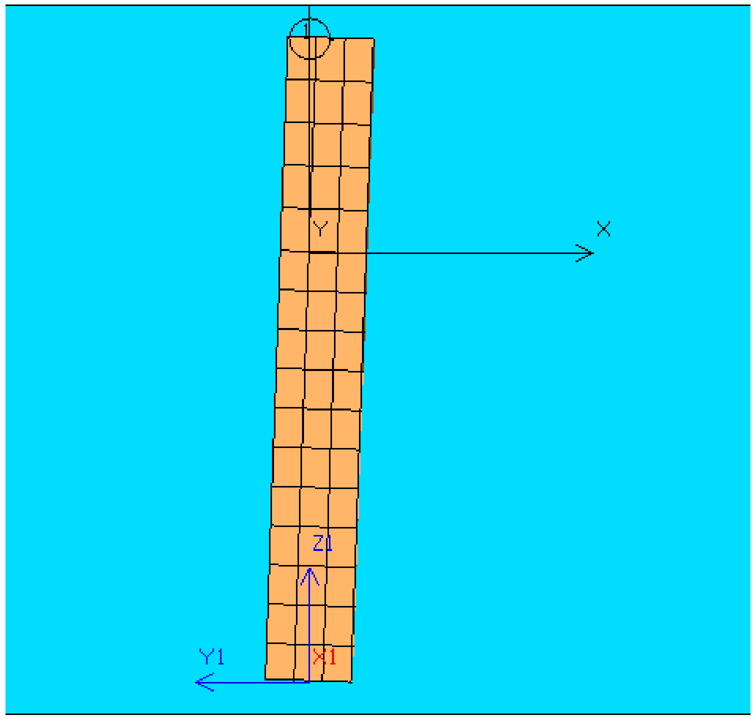
Figure 14. AQWA Pile Model P1 (Perspective View)

This pile is connected to the seafloor in the AQWA model and the stiffness and damping can be specified an input. For example, the stiffness value input to AQWA could include a number of factors such as the effective bending of the pile system and the interaction of the pile system with the seafloor sediments. Damping could include things like structural/mechanical damping, soils dampening effects and fender damping.

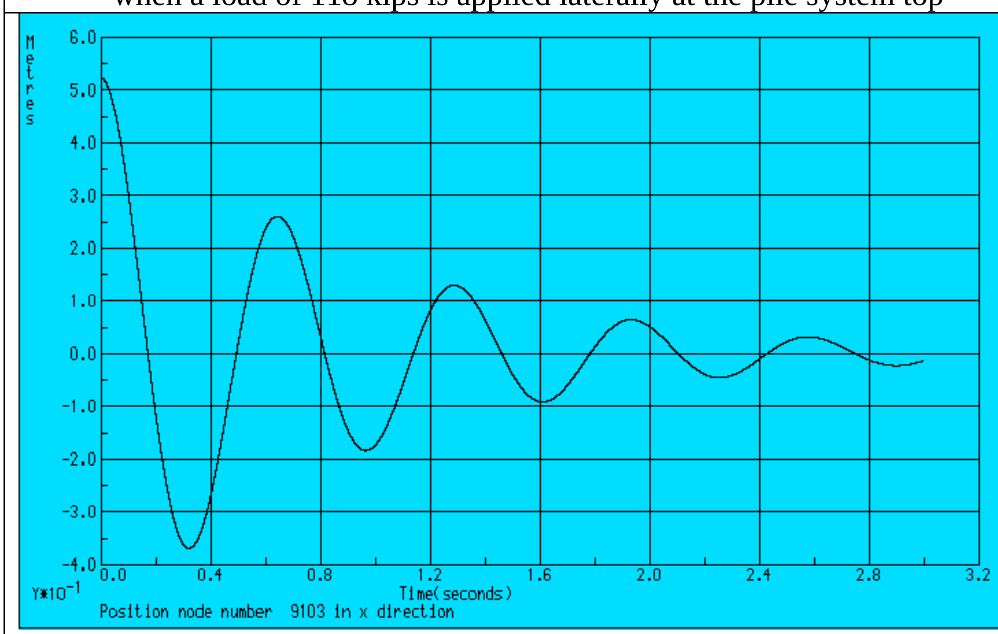
For example, take the case of a 15m (50 ft) pile extending from the seafloor to its top. A rotational stiffness is initially specified at the point where the pile system enters the seafloor so that the pile top deflects approximately 0.51m (1.67 ft) when a load of 118 kips is initially used to pull the pile laterally at the top (Figure x upper). Once the load is suddenly released, then the pile oscillates until the motion dampens out. Figure 15 lower shows a possible dampening scenario.

The dynamic behavior of the pile system depends on its length, mass, stiffness and the amount of damping specified.

In general pile systems tend to have much smaller mass than the berthing ferry and/or platform. Also, pile systems tend to be somewhat stiff. Therefore, the natural periods of pile systems (for example in bending) tend to be relatively short. Deflection of pile systems tend to be somewhat small, therefore fender compression/deflection will often tend to be relatively large compared to pile system deflection.



One possible pile stiffness – 15m long pile system deflects 1.67 ft at the top when a load of 118 kips is applied laterally at the pile system top



Pile P1 system behavior for a specified amount of stiffness and dampening (Natural period = 0.65 sec; does not include fender effects)

Figure 15. Pile Model P1 Under Load and Damping When Released

This effective pile system can be modeled as a Morrison or diffraction structure; it will not make much difference because the pile system does not make much in the way of waves as the pile moves (pile systems tend to move a small amount and the piles are small, so these combined effects do not make much in the way of waves).

Meanwhile, fenders are placed between the float platform and pile. For example, the load/deflection curve of the fenders can be specified. For the initial calculations various linear fender stiffness values will be assumed.

Other pile models, if need in this study, will be developed later in appendices.

5.0 BERTHING ANALYSES

In initially we start with four classes of Alaska ferries, the concrete float F1 and 15m long pile in a water depth of 10m (Pile P1). In engineering "Force = mass times acceleration" is a key concept. Also, in U.S. Naval Academy Lesson 4 we found that kinetic energy is key and kinetic energy is equal to (1/2) times mass times velocity squared (i.e. Eq (1)).

We know mass is therefore important to berthing, so Figure 16 and Table 3 shows the in-air masses involved. In the initial models the ferries FVF, M/V AURORA and M/V TAKU have approximately linearly increases in masses. However, M/V KENNICOTT is over an order of magnitude more massive than FVF. Meanwhile, concrete float F1 has approximately the same mass as FVF and much less mass than M/V KENNICOTT. Pile P1 has relatively little mass.

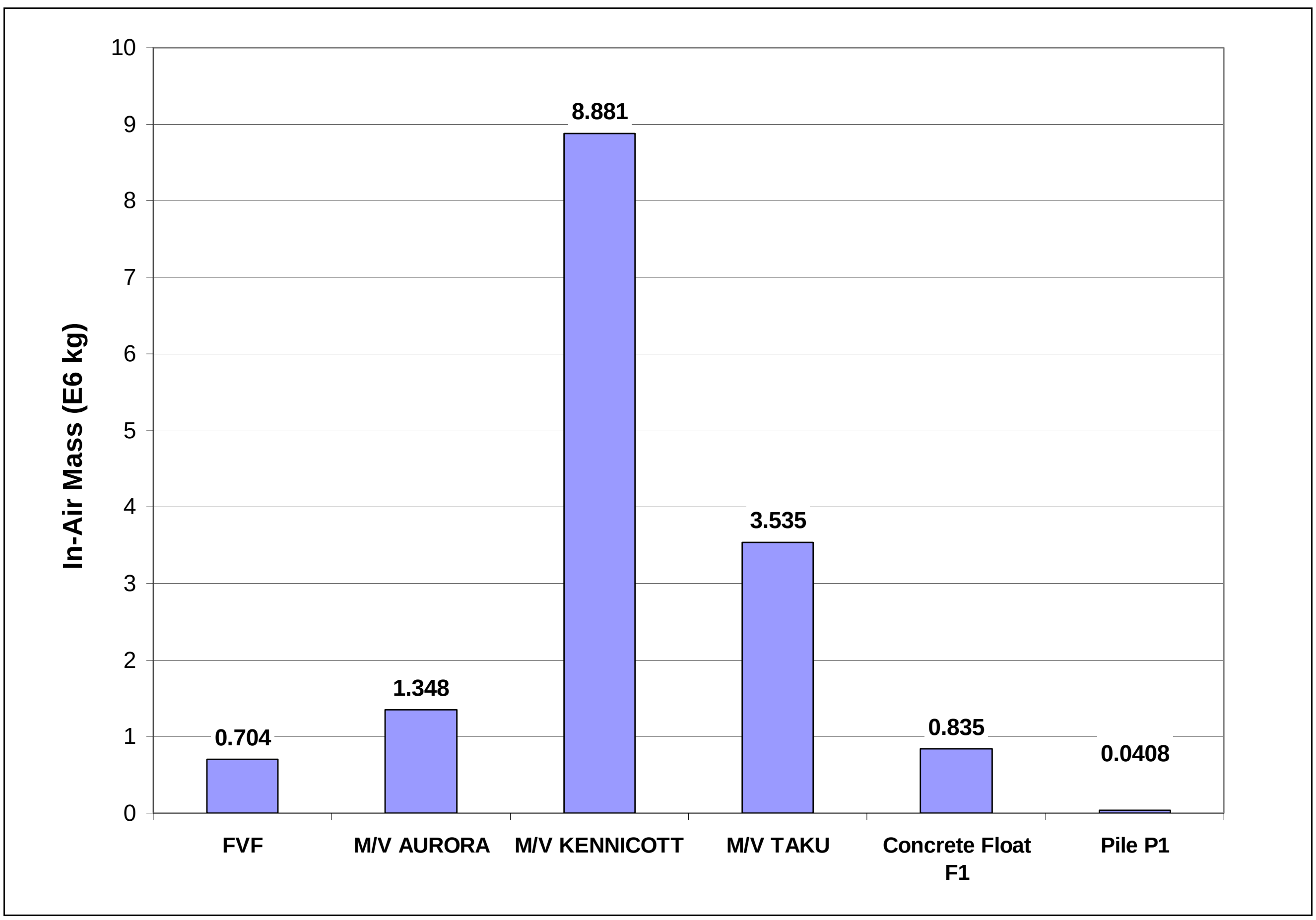


Figure 16. Initial Models Considered

Table 3. Initial Models Considered

SHIP	LENGTH (m)	WIDTH (m)	DRAFT (m)	MASS (E6 kg)	NOTES
Fast Vehicle Ferry (FVF)*	72.200	13.260	2.420	0.704	Catamaran
M/V AURORA	64.000	16.764	3.886	1.348	Mono-hull
M/V KENNICOTT	115.230	25.880	4.870	8.881	Mono-hull with Bulbous Bow
M/V TAKU	106.200	22.560	4.570	3.535	Mono-hull (scaled from AURORA)
Float F1 (Concrete)	18.288	18.288	2.438	0.835	Float concrete 60'x60'x10' with 2' freeboard
Pile P1 (15m long in 10m water)	2	2	10	0.0408	Pile 2m X 2mx X 15m
**** actual WL width of 2 hulls=8.57m***					

U.S. Naval Academy Lesson 1 shows that AQWA LINE diffraction analyses give good representation of the added masses of water that are entrained with vessels during berthing for the Alaska case (Figure 17).

For the U.S. Navy case (for example, a nuclear submarine SSN) the vessels stay at sea a long time, so when they come in to port they berth in the sway direction so they can be tied up securely and stay in port a long time. Also, Navy ports tend to be relatively shallow. Therefore, berthing coefficients (Cm, see Eq (2)) for submarines tend to be high. This means that hydrodynamic effects tend to be large for U.S. Navy berthing cases.

Alaska ferries tend to remain at site when working for a short time, unlike the typical U.S. Navy case. Also, ferries are loading/unloading vehicles when in operation, so berthing longitudinally (in the surge direction) often makes sense.

Figure 17 shows added mass coefficients for the Navy and Alaska cases. Both surge and sway added mass coefficients are shown for the four Alaska ferries considered. In the surge direction all of the Alaska ferries have added mass coefficients of Cm ~ 1. This means that there is not much added mass of water entrained with the ferry in the surge direction. The only kinetic energy that needs to be dissipated in the berthing process is due to the ferry alone. In surge berthing calculations we therefore do not expect the ferry hydrodynamic effects to have much influence. In surge calculations we only expect water hydrostatics to be important (i.e. the main effect of the water is to keep the ferry and platform floating).

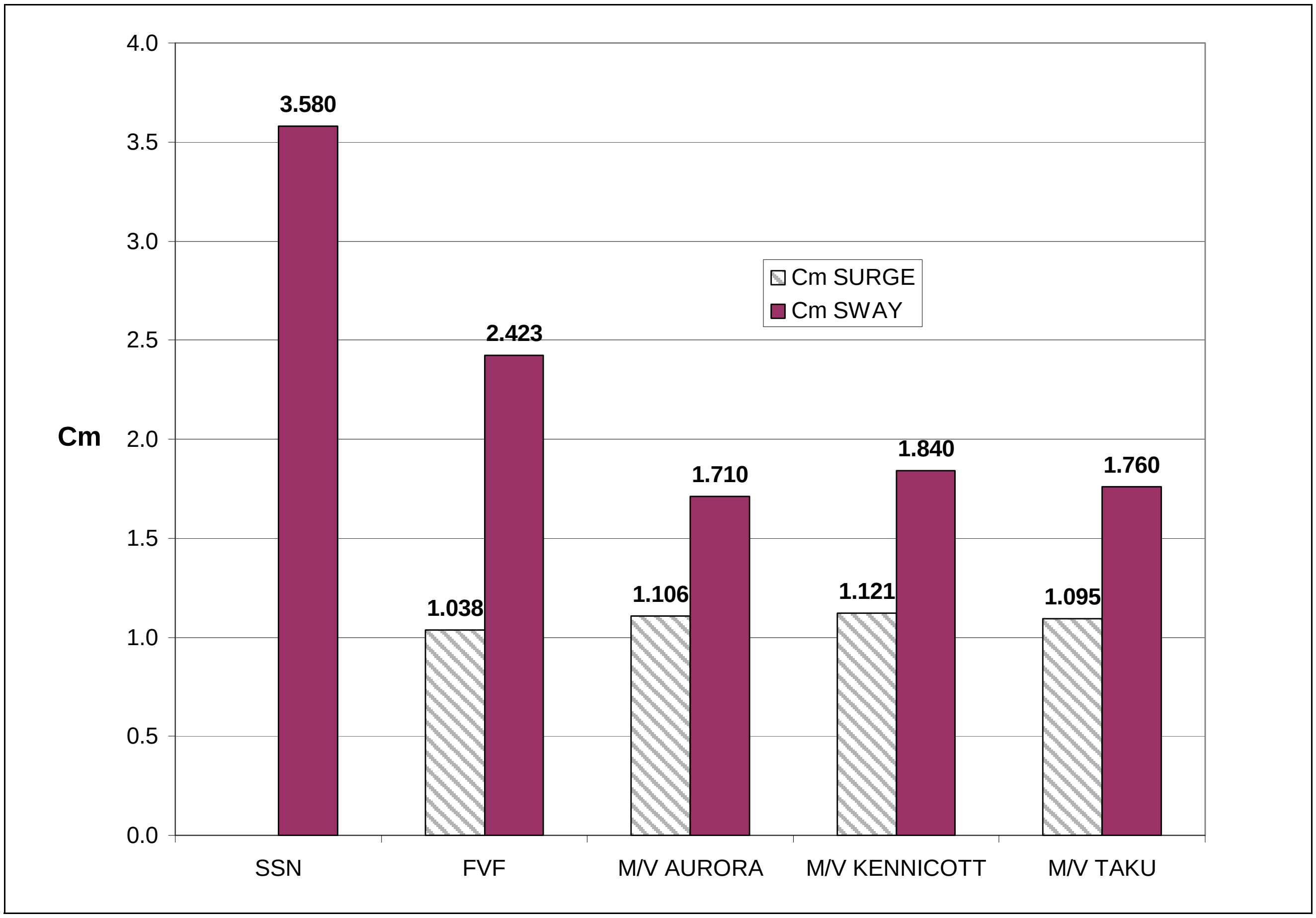


Figure 17. Values of Cm at Low Frequency (Surge-Surge and Sway-Sway)

Inspection of Figure 17 suggests that hydrodynamic effects are likely more important for the case of sway berthing. Fortunately, these effects are still expected to be less than in U.S. Navy berthing, because the large under-keel clearance typical in the Alaska case keeps down the amount of sway added mass of water.

Note that FVF has the highest added mass coefficient in sway of the four classes of Alaska ferries considered. This is because FVF is a catamaran and the actual two waterline widths of the two hulls is relatively small compared to the FVF length and draft. Therefore, the two hulls behave somewhat line two plates, compared to mono-hulls. U.S. Navy work shows that the closer a vessel comes to approaching a plate, the greater the added mass coefficient.

Many different combinations of parameters can be investigated in this study. To keep track of the analyses and the associated files, the following notation is used to name files:

Sample File Name = AD311XVK.dat

A = AQWA
D = dynamic AQWA simulation in the time domain
3 = Ferry number (1=FVF; 2=AURORA, 3=KENNICOTT, 4=TAKU)
1 = Float number (1 for concrete float F1)
1 = Pile number (1 for pile P1)
X = surge analysis (use Y for Sway)
V = ID to identify incoming ferry velocity
K = ID to keep track of specific other parameters, such as fender stiffness

The following analysis procedure is followed:

- Develop AQWA models of individual elements (see Section 4 or appendices if additional elements are needed).

- Run the diffraction program AQWA LINE and make a *.HYD file to retain hydrodynamic and hydrostatic properties of floating structures as six-by-six matrices or parameters as a function of frequency and direction. A water depth of d=10m is used. For the relatively deepwater Alaska cases the water depth effects on hydrodynamics in not important, so the same hydrodynamic parameters can be used throughout the study.

- Put the various elements together to perform berthing dynamic analyses. Analyses are performed in the time domain using a very small time step to accurately simulate and capture non-linear and transient effects.

- Run simulations in systematic way varying one parameter at a time to determine its effect.

A typical AQWA dynamic file (Figure 18) set-up includes:

Structure 0 = World. The world is taken as having a fixed right-handed axis system X = 0 at the initial pile position and X+ in the direction that the pile bends when hit; X is parallel to the still water surface. Y = perpendicular to direction of ferry hit and parallel to the still water surface. Z = upward from the water surface with Z = 0 at the still water surface. AQWA Nodes 9001 and 9002 are points where the pile attaches at the seafloor.

Structure 1 = Pile. For example P1 for Pile 1. This structure has its own local coordinate system. AQWA Nodes 9101 and 9102 are points on the pile where the pile attaches to the seafloor. AQWA Nodes 9111 and 9112 are points on the pile where the float hits the pile. Note that if you apply some static load on the pile at the water level, then the pile will deflect some value that the user specifies. This is stiffness k1 and it is initially assumed to be approximately linear.

Structure 2 = Float. This structure has its own local coordinate system. AQWA Nodes 9211 and 9212 are points on the float where the float hits the pile. A fender is assumed between the pile and float. This is stiffness k12 and it is initially considered to be linear.

Structure 3 = Ferry. This structure has its own local coordinate system. AQWA Nodes 9311 and 9312 are points on the ferry where the ferry hits the float. The AQWA nodes on the float at the ferry hitting point are 9213 and 9214.

A fender is assumed between the ferry and float. This is stiffness k23 and it is initially considered to be linear.

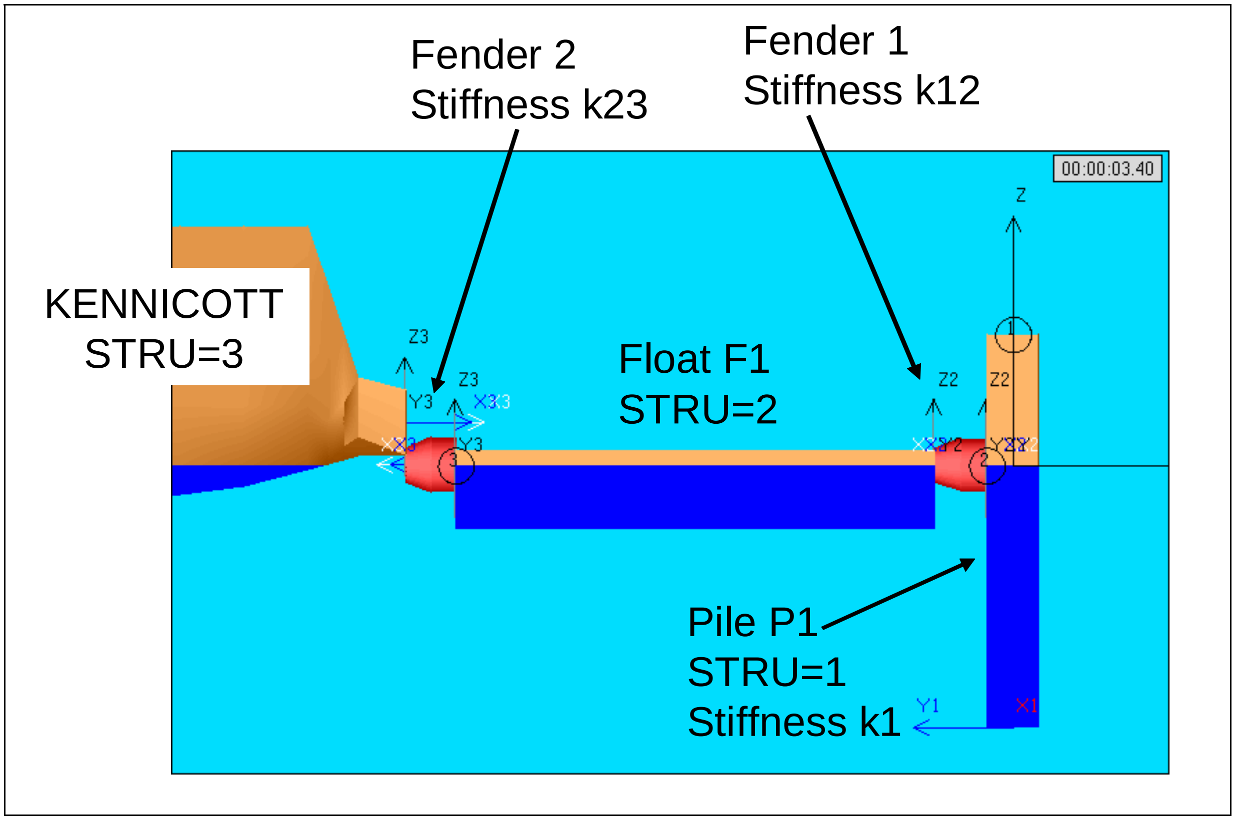


Figure 18. Sample AQWA Berthing Setup in Side View At Time of First Impact

For the above situation if the ferry pulls up and berths with approximately V ~ 0 and then gradually increases the propeller thrust / force, F, then the total system will deflect a certain linear amount in the direction of thrust. This deflection is caused by the combined deflection of the pile, fender between pile and float and fender between float and ferry. The static stiffness of the total system, k, from the ferry's point of view is:

$$k = 1 / ((1/k1) + (1/k12) + (1/k23)) \qquad \text{Eq (3)}$$

For example, for the special case of the pile stiffness, first fender stiffness and second fender stiffness being equal, then the total system stiffness in the lateral direction from the ferry's point of view is one-third the stiffness of each element.

Stiffness values are initially assumed to be linear, the effects of the rate of fender loading on stiffness are neglected, damping is neglected (except for the pile structural damping and float hydrodynamic effects) and fender frictions are neglected.

Note that two different peak forces are recorded for each AQWA dynamic simulation (Figure 18):

F12 = force on the pile (i.e. in the fender between the pile STRU=1 and float STRU=2)

F23 = force in the fender between the float STRU=2 and ferry STRU=3.

In the first few series of simulations only pure surge or sway are considered and the ferry berths "head on". In this case there is no yaw moment on the float or pile system, so they only surge, heave and pitch (i.e. no sway, roll or yaw).

5.1 SERIES 1 TO INVESTIGATE THE EFFECTS OF SURGE BERTHING VELOCITY M/V KENNICOTT

In SERIES 1 we investigate the effects of initial ferry velocity in surge on peak pile and fender loads. The four classes of ferry considered are relatively streamlined in the surge direction, so the thrust of the ferry is assumed to be turned off the instant before the ferry initially hits the berthing facility. The following velocity identifier "V" values are used in files:

IDENTIFIER "V"			
	Surge Velocity		
"V"	(knots)	(ft/sec)	(m/s)
a=	0.2	0.34	0.1030
b=	0.4	0.68	0.2059
c=	0.6	1.01	0.3089
d=	0.8	1.35	0.4118
e=	1.0	1.69	0.5148
f=	1.2	2.03	0.6177

For the fender case "A" is defined for all three fenders having the same stiffness.

IDENTIFIER "K"				
	Fender Stiffness (E6 N/m)			
	Width (m)=	2.00	2.00	
	Pile	Pile/Float	Ferry/Float	System
"K"	k1	k12	k23	k
A=	1.544	1.544	1.544	0.515

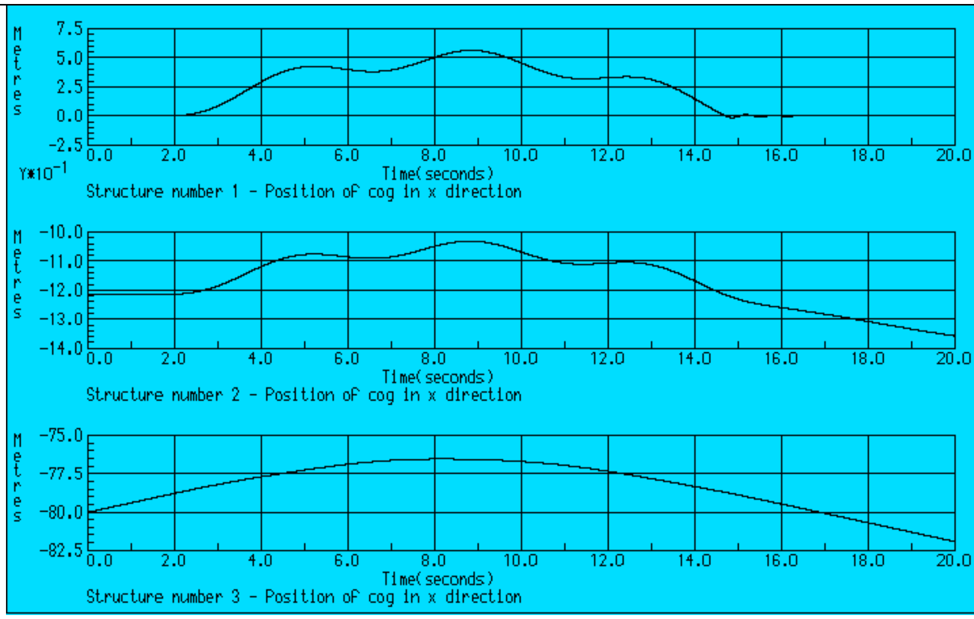
For Pile 1, Float 1, Ferry 3=KENNICOTT, longitudinal berthing and maximum berthing velocity this is file: AD311XfA.dat. Figure 18 shows this case just as the ferry starts to impact the system. Figure 19 shows results where the x-axis is time. Figure 19 (upper) shows structure position and Figure 19 (lower) shows fender loads. The ferry (Structure 3) hits fender23 and it starts to take up load, the float (Structure 2) starts to move and starts to load up the pile (Structure 1). The mass of the float causes a phase lag of about 2 seconds of the peak load in fender23 to fender12. However, the peak loads in all the system is about the same because KENNICOTT is so massive and moving at high speed for case "f" with an incoming surge velocity backing down of 1.2 knots.

Figure 20 shows KENNICOTT results for various berthing speeds for the stiffness case “A” (i.e. stiffness of each of 3 elements the same). When KENNICOTT berths at the platform there is an initial peak load. When the platform then berths into the pile system there is a reduced peak load reduction of approximately 2.5% because there is some momentum transferred from KENNICOTT into the float. Note that even at the maximum ferry speed modeled of 1.2 knots the peak float F1 velocity is 0.6 m/s for a small fraction of a second (1.1 knot; Figure 19 lower portion, upper curve).

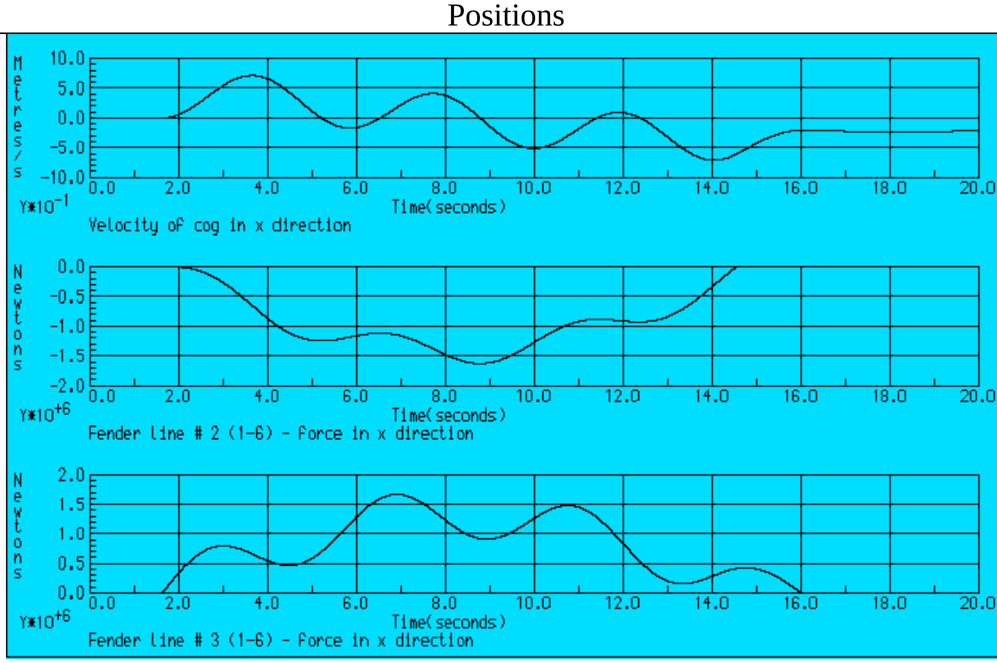
To define the kinetic energy use (1/2) * mass * V2 where V is incoming ship velocity and mass is only the ship mass. Figure 20 shows that the peak loads are not quite linear as a function of kinetic energy because of the complexities of various masses, added masses, damping involved, etc.

The influence of the concrete float F1 is examined next by removing it (Figure 20), which is the “0” case, so a typical file is AD301XfA.dat. Here we keep the overall fender stiffness the same as Case “A (i.e. In this case the fender between M/V KENNICOTT and pile P1 is twice as wide and half as soft as case AD311XfA.dat to get the same overall system stiffness from the ferry point of view).

Removing the float F1 actually drops the peak fender loads approximately 15%, as shown in Figure 21, even though the overall system stiffness is the same in both cases. This is because there are a number of competing factors involved. With the float F1 M/V KENNICOTT initially berths at the float and the fender between the ferry and float is somewhat stiff. It only takes a short time for the float to start moving, which relieves the load in the initial fender, but meanwhile the peak load in that first fender is somewhat high for a short duration. This slightly higher load in then transferred into the pile. Without the float F1 the system looks dynamically “softer” to the ferry, even though the static system stiffness is the same for cases AD311XfA.dat and AD301XfA.dat.



Positions



Concrete Platform Velocity and Fender Loads

Figure 19. Sample AQWA Berthing Results
(Largest Ferry at Maximum Speed; Stiffness of each fender element the same; Concrete Float F1; File: = AD311XfA.dat)

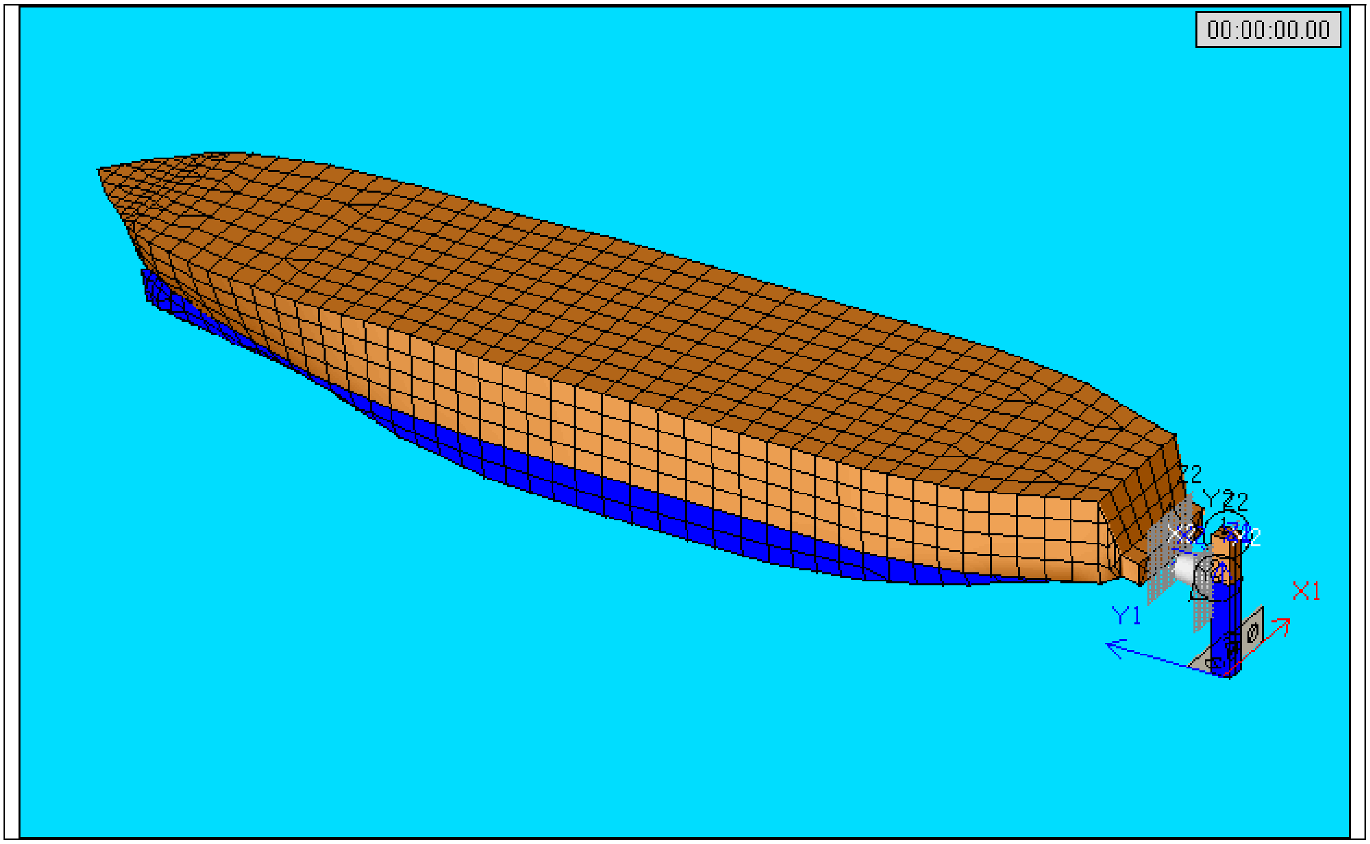
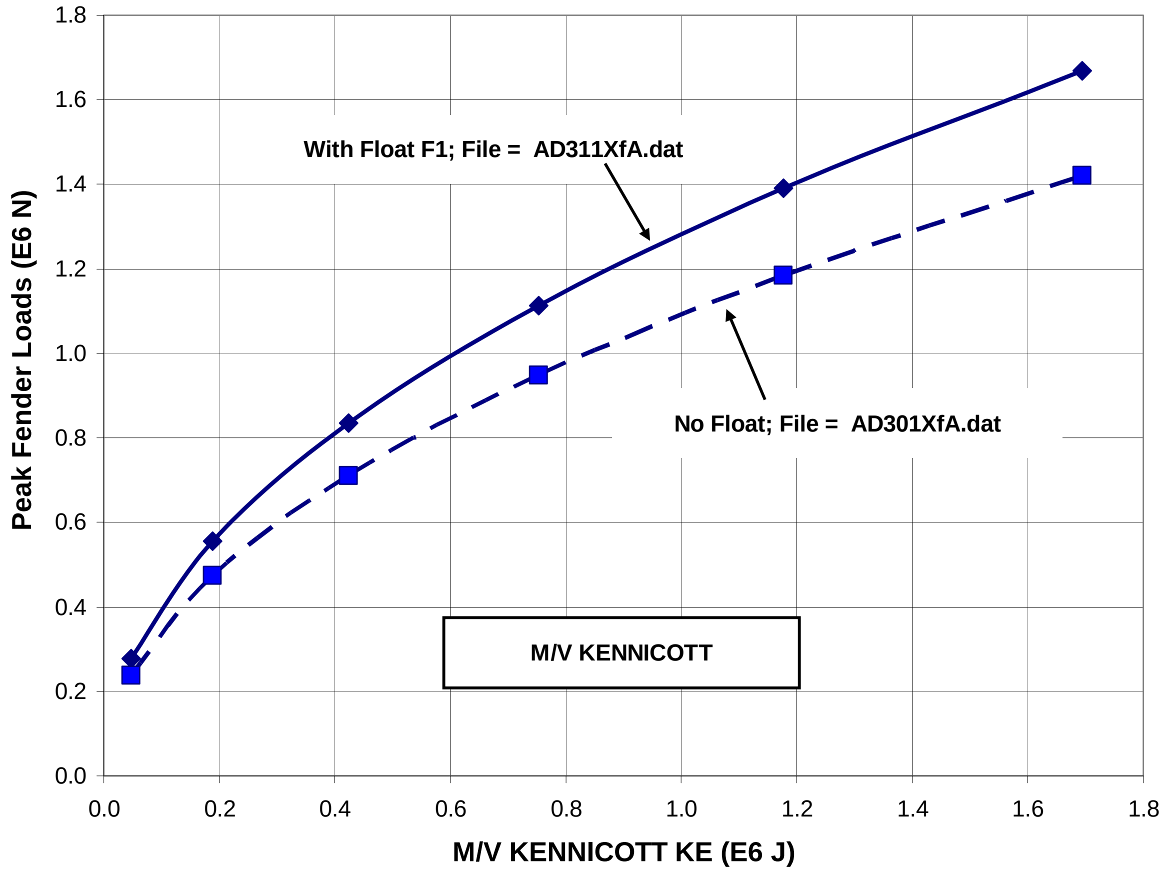


Figure 20. AQWA Model with the Concrete Float F1
(Largest Ferry at Maximum Speed; Stiffness of each fender element the same; Sample File =No Float; File: = AD301XfA.datl; i.e. same as file AD311XfA.dat but without the float)



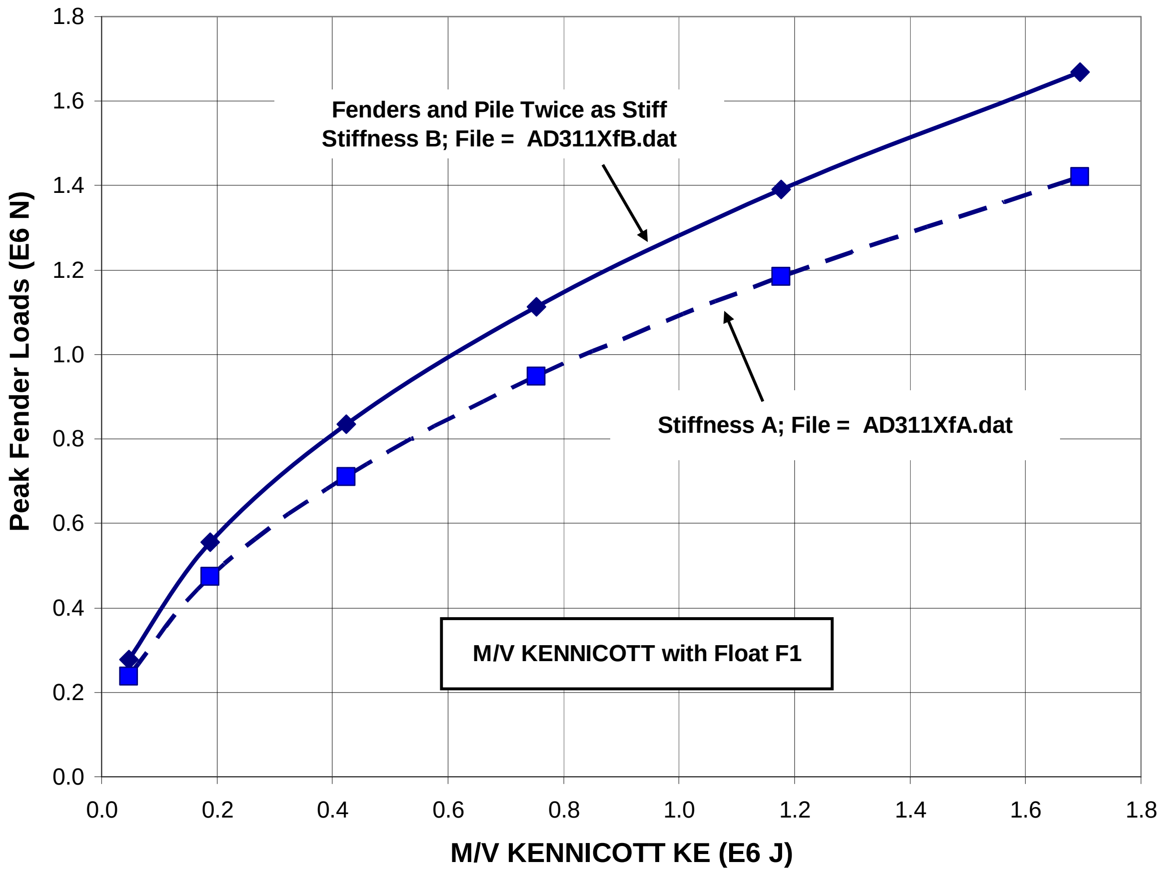
	ex. AD311XfA.dat					ex. AD301XfA.dat		
	Peak Fender					Peak Fender		
	Loads (E6 N)					Loads (E6 N)		
	Fender A (3 equal stiffnesses)					Fender A		
KE (E6 J)	k12	k23	Diff (%)		KE (E6 J)	k13		
0.0471	0.27828	0.27161	2.40%		0.0911	0.2372		
0.1882	0.55621	0.54278	2.41%		0.3639	0.47406		
0.4235	0.83432	0.81407	2.43%		0.8189	0.71107		
0.7529	1.1122	1.085	2.45%		1.4552	0.94776		
1.1764	1.3902	1.356	2.46%		2.2736	1.1846		
1.6940	1.668	1.627	2.46%		1.6940	1.4212		
3-KENNICOTT, 1-CONCRETE; 1-PILE P1;					3-KENNICOTT, 0 PLATFORM 1-PILE P1;			
A-EQUAL PILE STIFFNESS					A-EQUAL PILE STIFFNESS			

Figure 21. M/V KENNICOTT with and without Float F1

For the next stiffness case B, let us keep float F1 and make the stiffness of each element (i.e k1, k12 and k23) twice as high (example file AD311XfB.dat) as the first case AD311XfA.dat :

IDENTIFIER "K"				
	Fender Stiffness (E6 N/m)			
	Width (m)=	2.00	2.00	
	Pile	Pile/Float	Ferry/Float	System
"K"	k1	k12	k23	k
A=	1.544	1.544	1.544	0.515
B=	3.088	3.088	3.088	1.029

In this system (example file AD311XfB.dat) both the fenders between ferry to float and float to pile again have approximately the same load (Figure 22 lower). However, doubling the static stiffness of each element increases the peak load by 41% (Figure 22 upper). Extra load on the pile occurs when a soft fender between the pile and float causes the float to pick up momentum and kinetic energy.

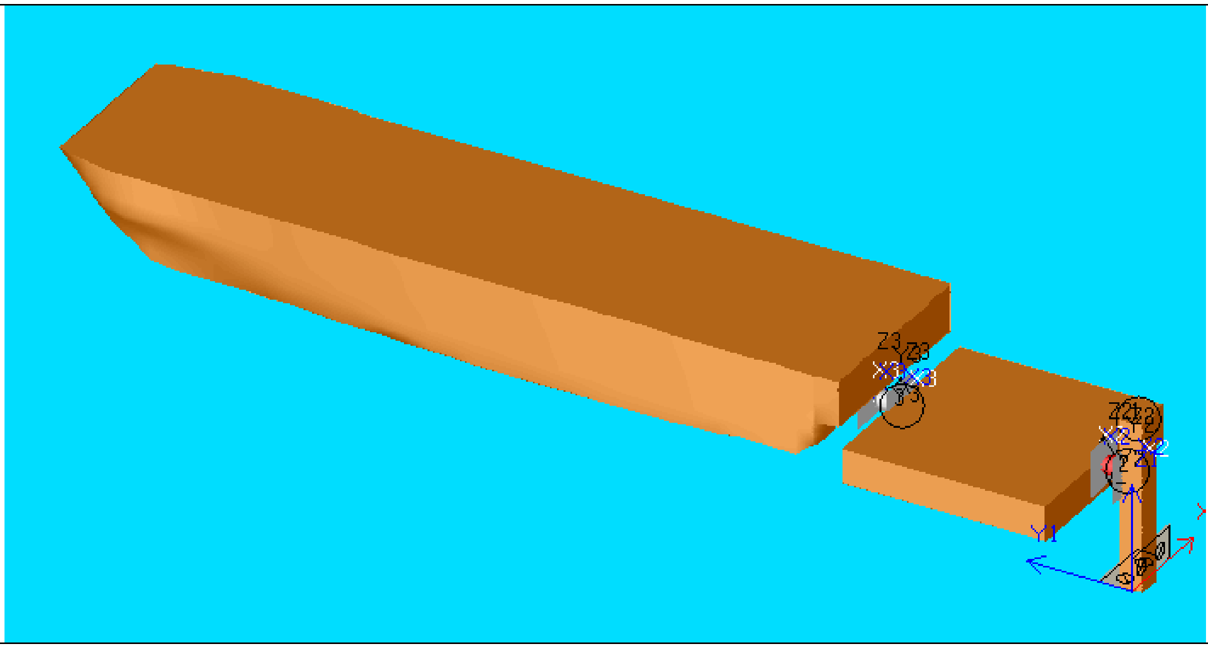


	ex. AD311XfB.dat		
	Peak Fender		
	Loads (E6 N)		
	Fender B (3 equal stiffnesses)		
KE (E6 J)	k12	k23	Diff (%)
0.0471	0.39337	0.38201	2.89%
0.1882	0.78619	0.76341	2.90%
0.4235	1.1795	1.145	2.92%
0.7529	1.5722	1.5262	2.93%
1.1764	1.9653	1.9075	2.94%
1.6940	2.3577	2.2882	2.95%

Figure 22. KENNICOTT Berthing Results For Stiffness "B" vs "A" (Example File: = AD311XfB.dat)

5.2 SERIES 2 TO INVESTIGATE THE EFFECTS OF SURGE BERTHING VELOCITY FVF

In SERIES 2 we investigate the effects of initial ferry velocity in surge on peak pile and fender loads using the lightest ferry, the catamaran Fast Vehicle Ferry (FVF). Here we start with the concrete float F1, which has more mass than FVF.



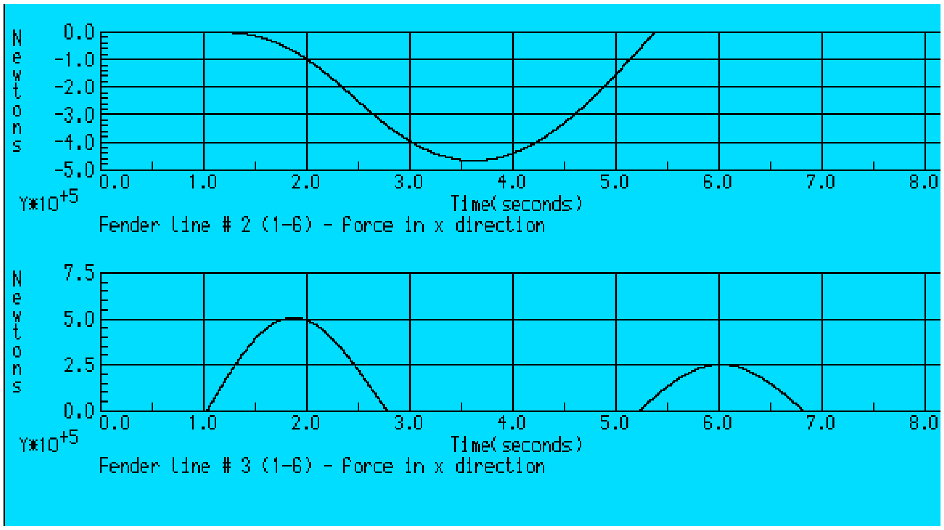


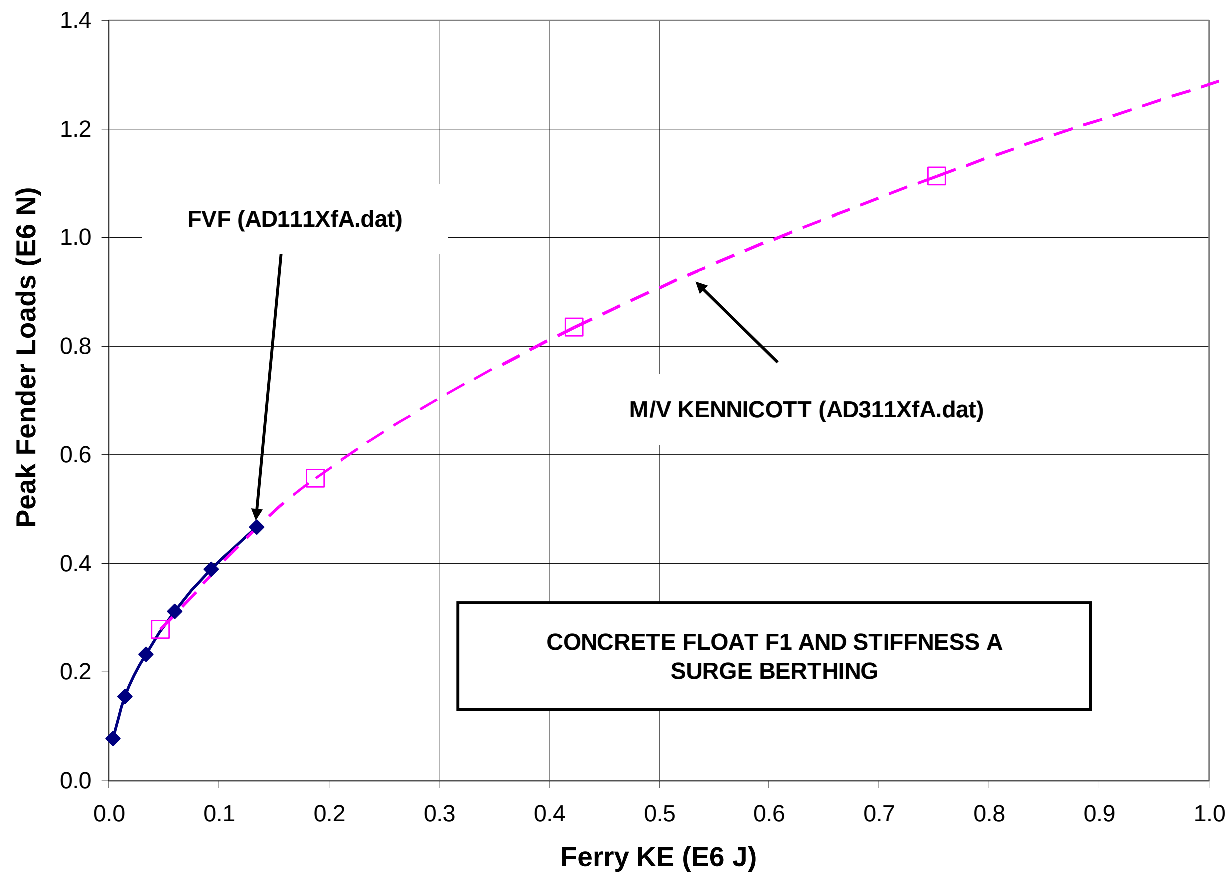
Figure 23. FVF Berthing at Concrete Platform F1 Loads for file AD111XfA.dat

Figure 23 lower shows fender predicted peak forces for the maximum FVF case of 1.2 knots, stiffness case A, Float F1 and FVF. As the ferry berths the first fender picks up load (bottom curve), the float starts to move, which relieves the load in the first fender, and then the second fender/pile system picks up load.

As with M/V KENNICOTT the peak loads in the two fenders are about the same, but there is slightly more difference for FVF (Figure 24 lower table), which is a very light vessel.

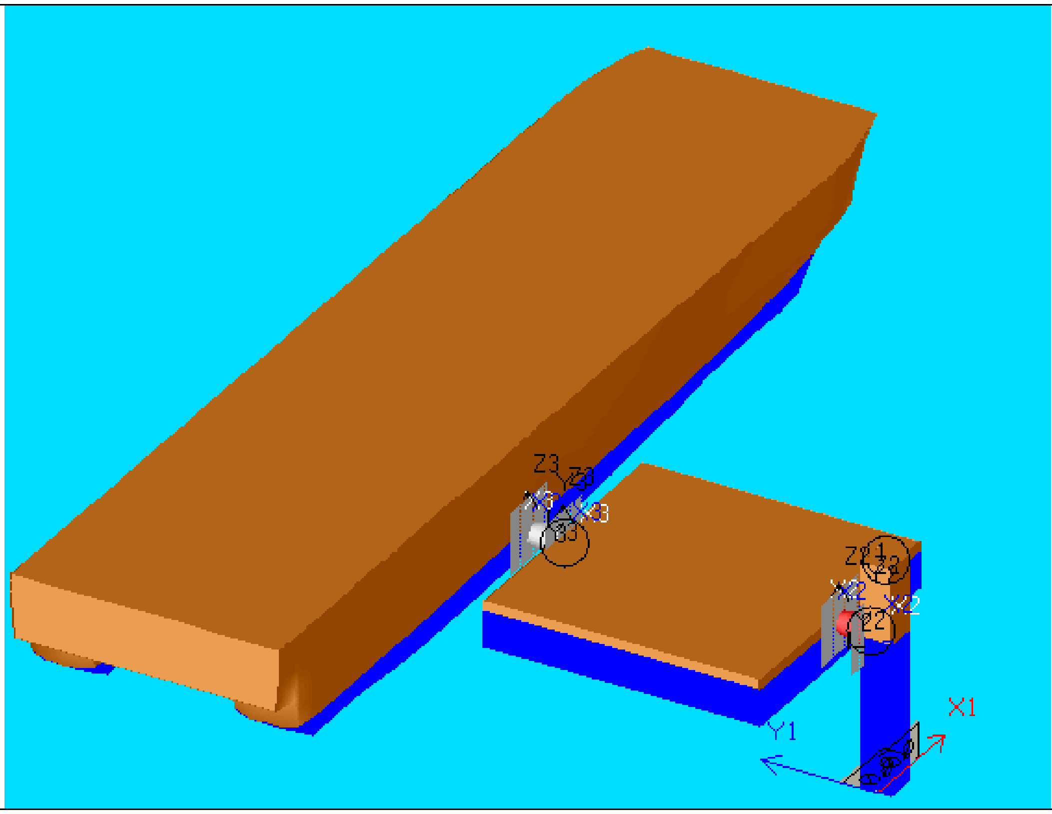
For the surge cases we define the kinetic energy of the vessel in terms of its in-coming velocity and mass only (i.e. neglect surge added mass, because it is small). For a given velocity the peak fender loads are much lower for FVF than M/V KENNICOTT, because FVF is over one order of magnitude lighter. However, for the case of the concrete float F1 and stiffness A, both FVF and M/V KENNICOTT have the same peak fender loads when plotted vs. vessel kinetic energy (Figure 24 upper).

The case of FVF berthing laterally is also analyzed (Figure 25). Notice that the peak load in the second fender by the pile is slightly higher than the peak load in the fender between ferry and float. In the case of sway the incoming kinetic energy is calculated to include the added mass of water using Eq (1) and Eq (2). Figure 26 shows that in terms of kinetic energy M/V KENNICOTT in surge, FVF in surge and FVF in sway all give the same peak berthing loads. The confirms U.S. Naval Academy LESSON 4 that for a given facility the berthing energy is key. This suggests that additional simulations need to focus on the facility and that different ferries in surge and sway do not need to be analyzed as long as an adequate range of incoming kinetic energies is considered.



FVF			
	ex. AD111XfA.dat		
	Peak Fender		
	Loads (E6 N)		
	Fender A (3 equal stiffnesses)		
KE (E6 J)	k12	k23	Diff (%)
0.0037	0.0779	0.0844	-8.34%
0.0149	0.15565	0.1687	-8.38%
0.0336	0.2335	0.2531	-8.39%
0.0597	0.3112	0.33738	-8.41%
0.0933	0.389	0.4218	-8.43%
0.1343	0.4667	0.5061	-8.44%
1-FVF, 1-CONCRETE; 1-PILE P1;			
A-EQUAL PILE STIFFNESS			

Figure 24. FVF Surge Berthing at Concrete Platform F1 Loads for file AD111XfA.dat



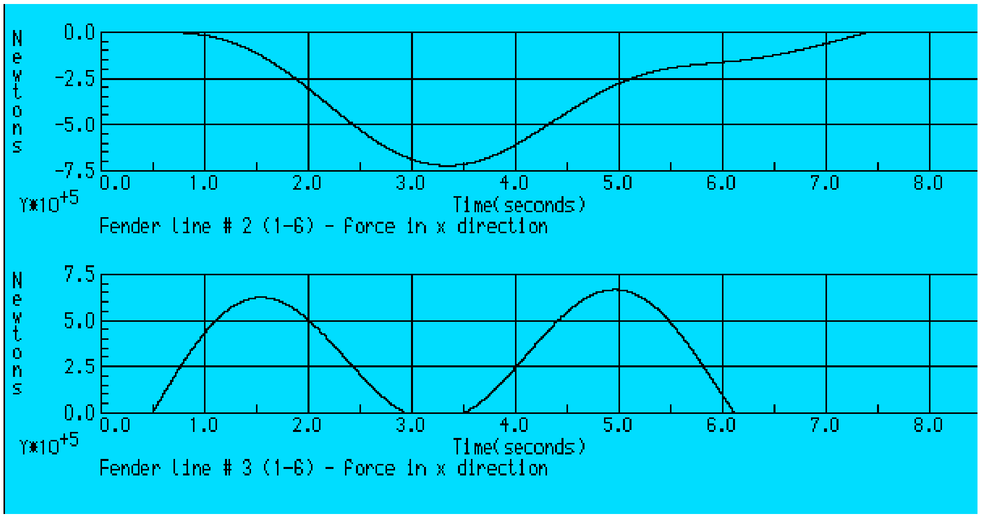


Figure 25. FVF Sway Berthing at Concrete Platform F1 (file AD111YfA.dat)

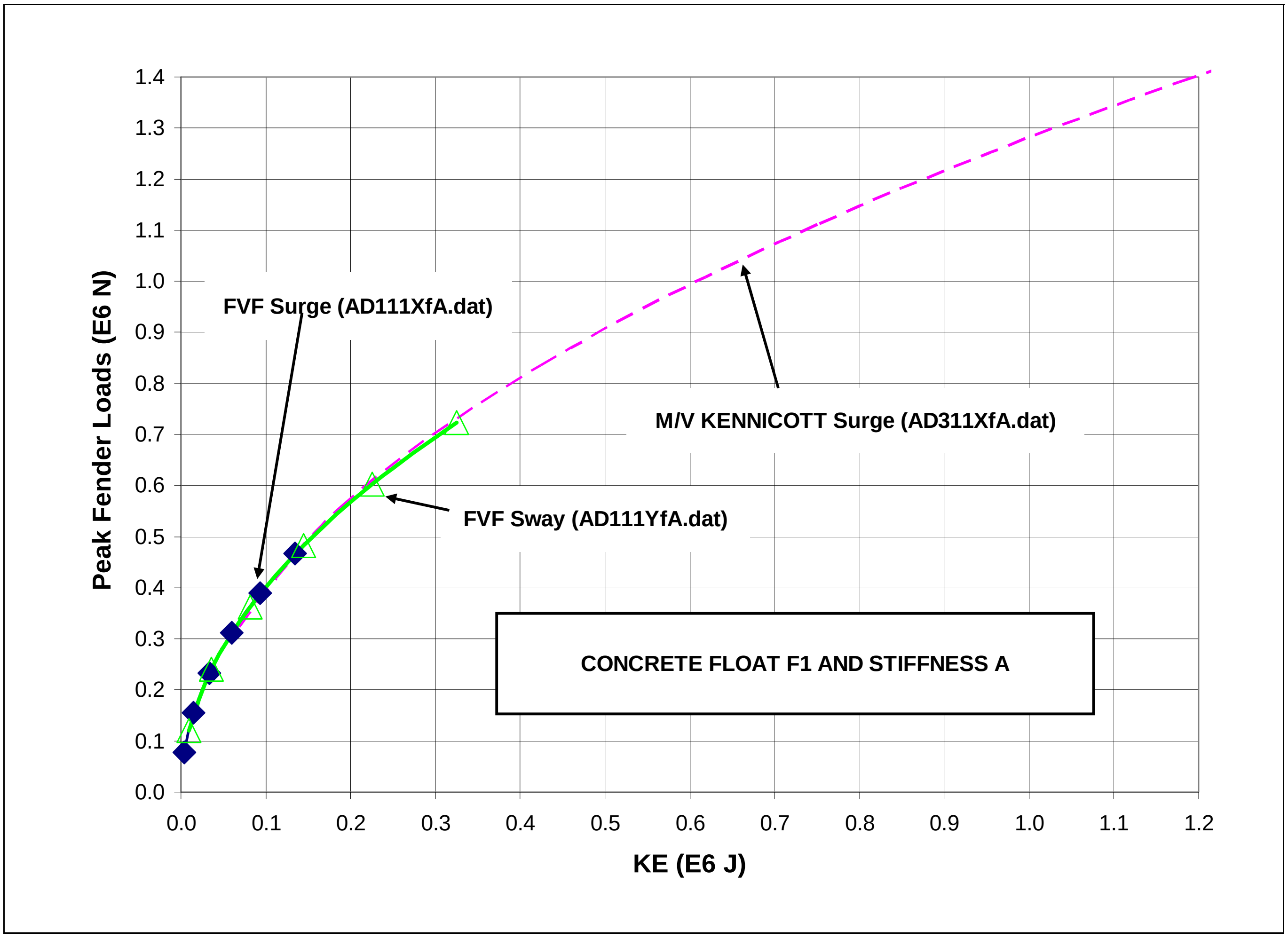


Figure 26. Berthing at Concrete Platform F1
Loads for Surge and Sway
(files AD111XfA.dat, AD111YfA.dat and AD311XfA.dat)

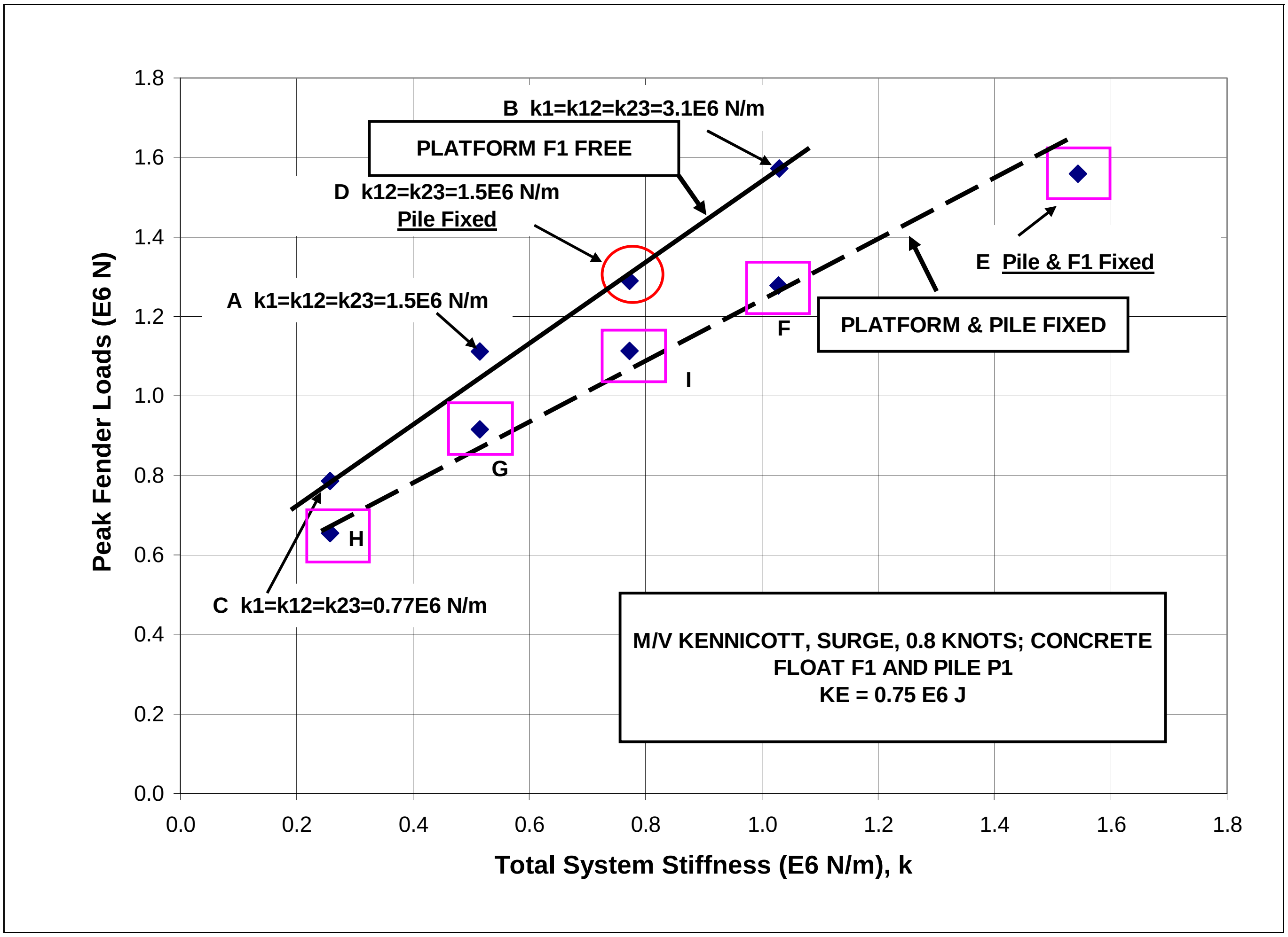
5.3 SERIES 3 TO INVESTIGATE STIFFNESS EFFECTS

In SERIES 1 and SERIES 2 we: (1) Started to investigate stiffness effects and found that it is important; (2) We learned that the details of the ship and its direction are not important , so in SERIES 3 we use M/V KENNICOTT in the surge direction; (3) We found that the float has some effect, for example, removing the float caused some reduction in peak berthing load, and (4) We found that the peak load between ferry and float is approximately the same as between float and pile system. In SERIES 3 we take the data already obtained from simulations and examine system stiffness effects in more detail.

In SERIES 1 an initial stiffness was used in "A" runs and the stiffness was doubled in "B". Here we run "C" with half the stiffness. Case "D" is then taken as the same as "A", except that the pile is made completely rigid (i.e. it is locked to the earth and not allowed to bend at all). Additional runs "E" through "I" model the case of float F1 fixed to a fixed pile P1.

Ship =	**M/V KENNICOTT**					
Direction =	**Surge**					
Float =	**Concrete F1**					
Pile =	**P1**					
	Component Static Stiffnesses					
		FENDER STIFFNESS	**FENDER STIFFNESS**	**TOTAL**		
STIFFNESS	**PILE STIFFNESS**	**PILE TO FLOAT**	**FLOAT TO FERRY**	**SYSTEM**		**SAMPLE FILE FOR**
SERIES	**k1 (E6 N/m)**	**k12 (E6 N/m)**	**k12 (E6 N/m)**	**k (E6 N/m)**	**NOTES**	**M/V KENNICOTT**
A	1.544	1.544	1.544	0.515	Equal stiffness	AD311XfA.dat
B	3.088	3.088	3.088	1.029	Equal stiffness	AD311XfB.dat
C	0.772	0.772	0.772	0.257	Equal stiffness	AD311XfC.dat
D	99999.0	1.544	1.544	0.772	Pile fixed	AD311XfD.dat
E	99999.0	99999.0	1.544	1.544	Pile fixed, F1 fixed to pile	AD311XfE.dat
F	99999.0	99999.0	1.029	1.029	Pile fixed, F1 fixed to pile	AD311XfF.dat
G	99999.0	99999.0	0.515	0.515	Pile fixed, F1 fixed to pile	AD311XfG.dat
H	99999.0	99999.0	0.257	0.257	Pile fixed, F1 fixed to pile	AD311XfH.dat
I	99999.0	99999.0	0.257	0.772	Pile fixed, F1 fixed to pile	AD311XfI.dat

For example, take the case of M/V KENNICOTT berthing in surge at 0.8 knot with float F1 and pile P1. Figure 27 shows that overall system stiffness is key. The upper curve is for float F1 with fenders between the pile and ferry. Even if the pile is fixed (red circle) the overall system stiffness controls. Meanwhile, if both the pile is fixed and float F1 is fixed to the pile, then the peak loads are reduced somewhat (dashed line). This suggests that the moving float causes some modest increase in peak berthing loads, with all other factors being equal.



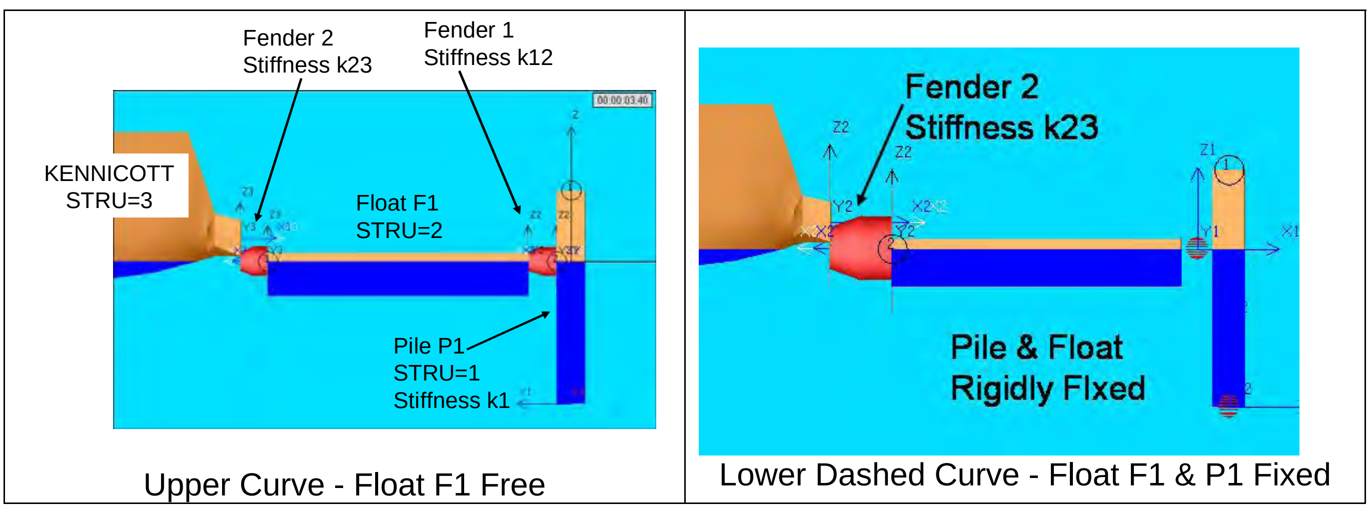


Figure 27. Effect of System Stiffness on Peak Fender Load

At this point the effect of the float F1 and P1 connection is investigated further by placing a hinge, rather than fender, between the float and pile (see Figure 28).

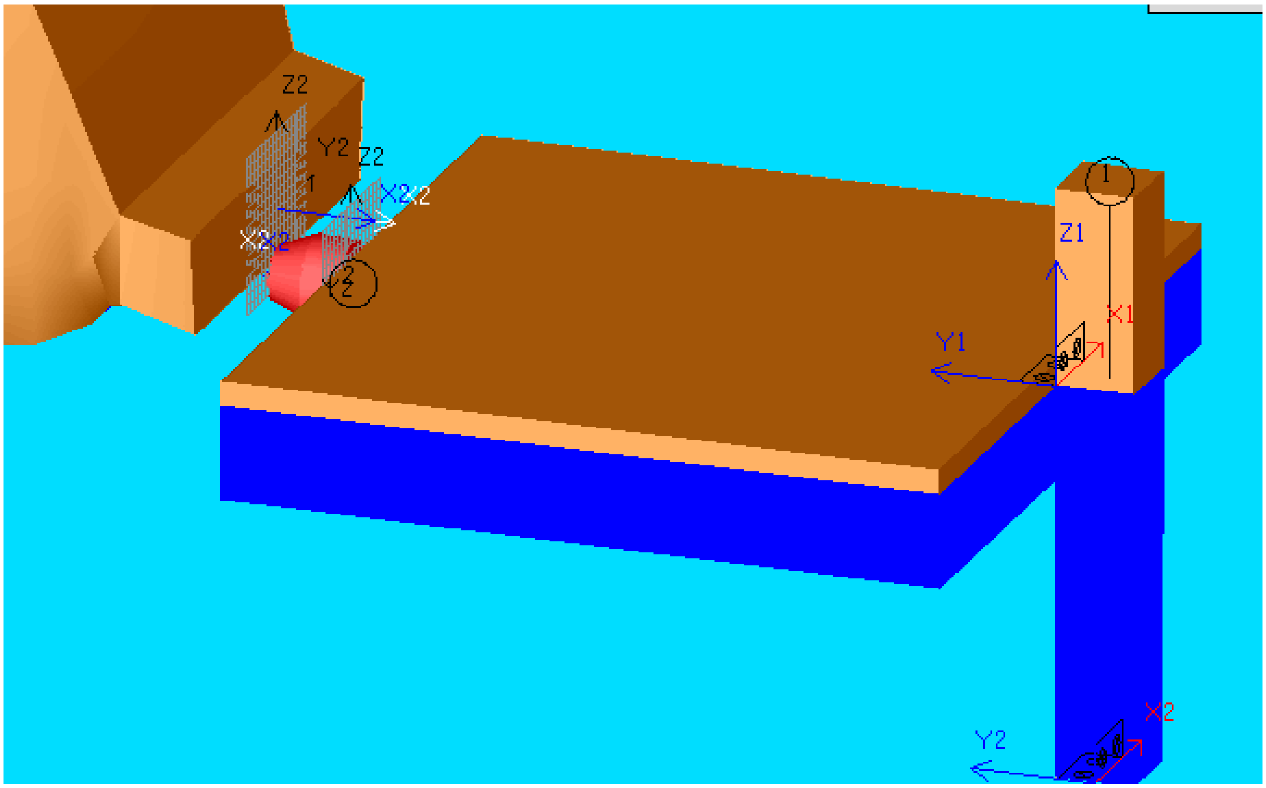
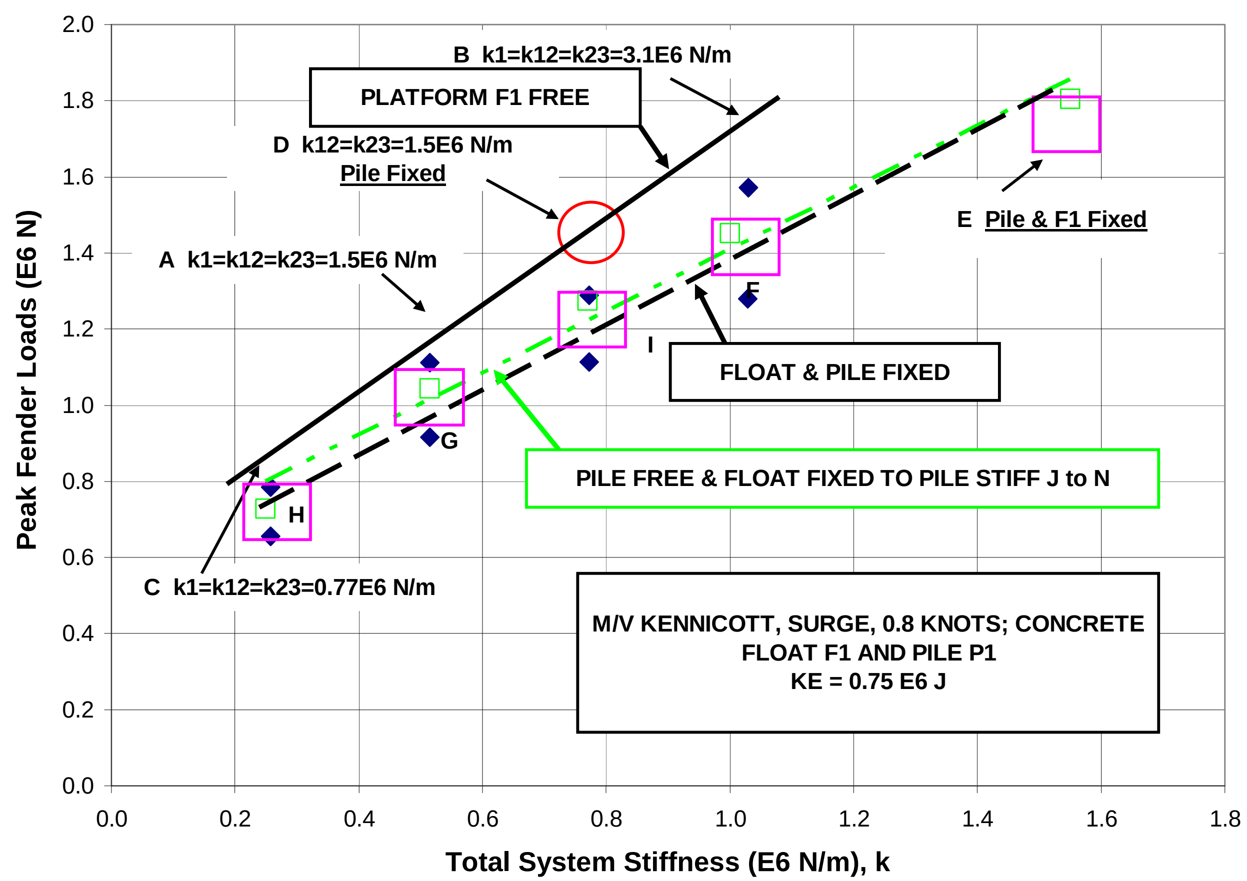


Figure 28. Float F1 Hinged to Pile P1
(Models AD311XfJ.dat to AD311XfN)

Results from these analyses (see dashed green line in Figure 29) show that it is best not to have much "play" or spring between float F1 and pile P1. Keeping this attachment tight in the plane parallel to the water level helps keep peak berthing loads down by reducing the momentum/kinetic energy that the float can pick up as berthing starts.



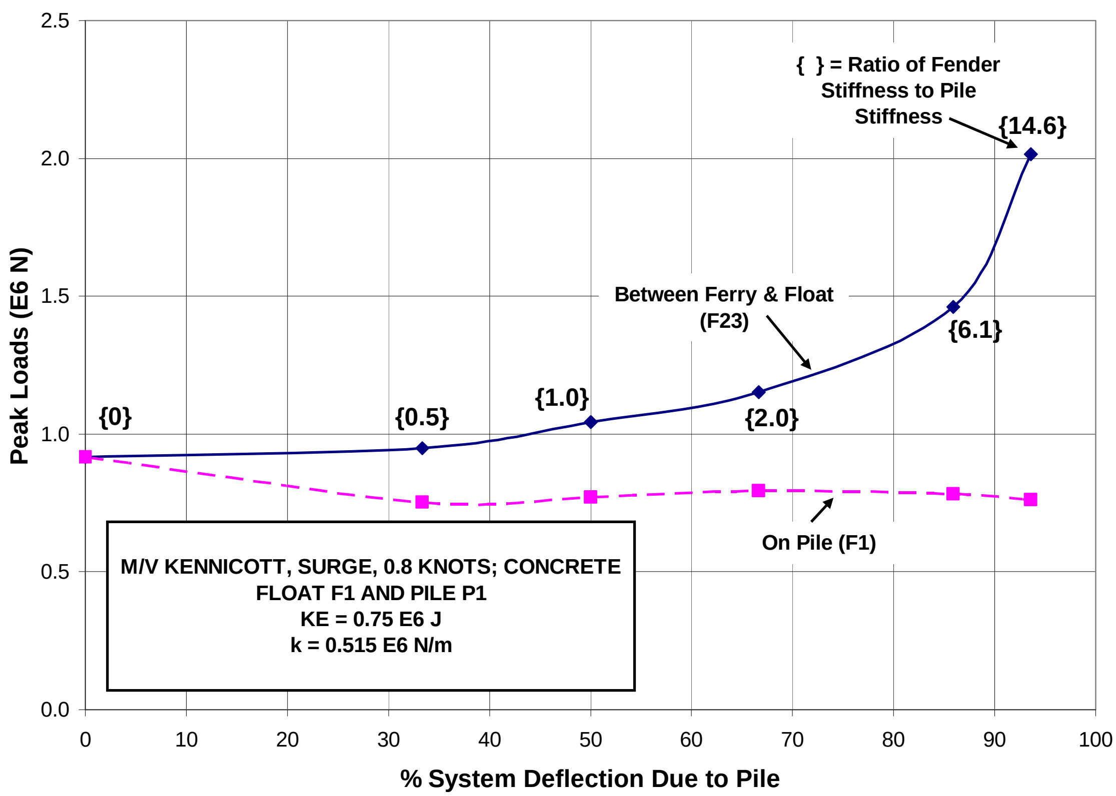
Ship =	M/V KENNICOTT						
Direction =	Surge						
Float =	Concrete F1						
Pile =	P1						
	Component Static Stiffnesses						PEAK FENDER
		FENDER STIFFNESS	FENDER STIFFNESS	TOTAL			FORCE (E6 N)
STIFFNESS	PILE STIFFNESS	PILE TO FLOAT	FLOAT TO FERRY	SYSTEM		SAMPLE FILE FOR	For d=0.8kts
SERIES	k1 (E6 N/m)	k12 (E6 N/m)	k12 (E6 N/m)	k (E6 N/m)	NOTES	M/V KENNICOTT	KE=0.75E6 J
A	1.544	1.544	1.544	0.515	Equal stiffness	AD311XfA.dat	1.112
B	3.088	3.088	3.088	1.029	Equal stiffness	AD311XfB.dat	1.572
C	0.772	0.772	0.772	0.257	Equal stiffness	AD311XfC.dat	0.786
D	99999.0	1.544	1.544	0.772	Pile fixed	AD311XfD.dat	1.289
E	99999.0	99999.0	1.544	1.544	Pile fixed, F1 fixed to pile	AD311XfE.dat	1.558
F	99999.0	99999.0	1.029	1.029	Pile fixed, F1 fixed to pile	AD311XfF.dat	1.279
G	99999.0	99999.0	0.515	0.515	Pile fixed, F1 fixed to pile	AD311XfG.dat	0.916
H	99999.0	99999.0	0.257	0.257	Pile fixed, F1 fixed to pile	AD311XfH.dat	0.655
I	99999.0	99999.0	0.257	0.772	Pile fixed, F1 fixed to pile	AD311XfI.dat	1.113
J	0.500	99999.0	0.500	0.250	Lock float F1 to pile	AD311XfJ.dat	0.728
K	1.030	99999.0	1.030	0.515	Lock float F1 to pile	AD311XfK.dat	1.044
L	1.540	99999.0	1.540	0.770	Lock float F1 to pile	AD311XfL.dat	1.275
M	2.000	99999.0	2.000	1.000	Lock float F1 to pile	AD311XfM.dat	1.451
N	3.100	99999.0	3.100	1.550	Lock float F1 to pile	AD311XfN.dat	1.805

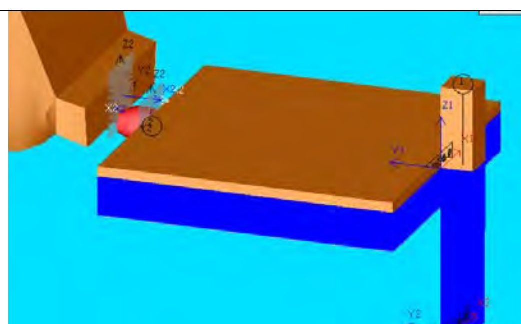
Figure 29. Float F1 Hinged to Pile P1 (Stiffness Files J to N)

Figure 29 also shows that it does not make much difference where the stiffness comes from. The black dashed line in Figure 29 is for cases where the pile and float are completely fixed, so the stiffness only comes from the fender between ferry and float. The green dashed line in Figure 29 is for the cases both the pile and fender provide some of the stiffness.

The previous runs show that it is best not to have a fender between the float and pile (Figure 28 shows this case), so at this point we therefore eliminate this fender. To understand the relation between the other stiffness values, we here keep both the kinetic energy of the in-coming ferry and the over-all surge system stiffness constants. The relative stiffness between the pile system (k1) and float-to-ferry fender (k23) are then systematically varied. Figure 29 plots fender and pile system peak loads as a function of the % of system deflection due to the pile system. Both the peak load on the pile at water level (F1) and peak load in the fender (F23) between ferry and float F1 and ferry are relatively constant over a wide range of conditions. However, for the case of almost all the system defection due to the pile, then the fender stiffness k23 gets very large. For this case the ferry hits the float quite hard for a short instant in time when first contact is made.

In most of the cases pile systems are expected to be stiff and marine fenders soft, we are in the left hand portion of Figure 30. Only in cases where the marine fender is very stiff compared to the pile system will the location of stiffness be important. For example, the cast on the right side of Figure 0 has the marine fender 14.6 times stiffer than the pile system.



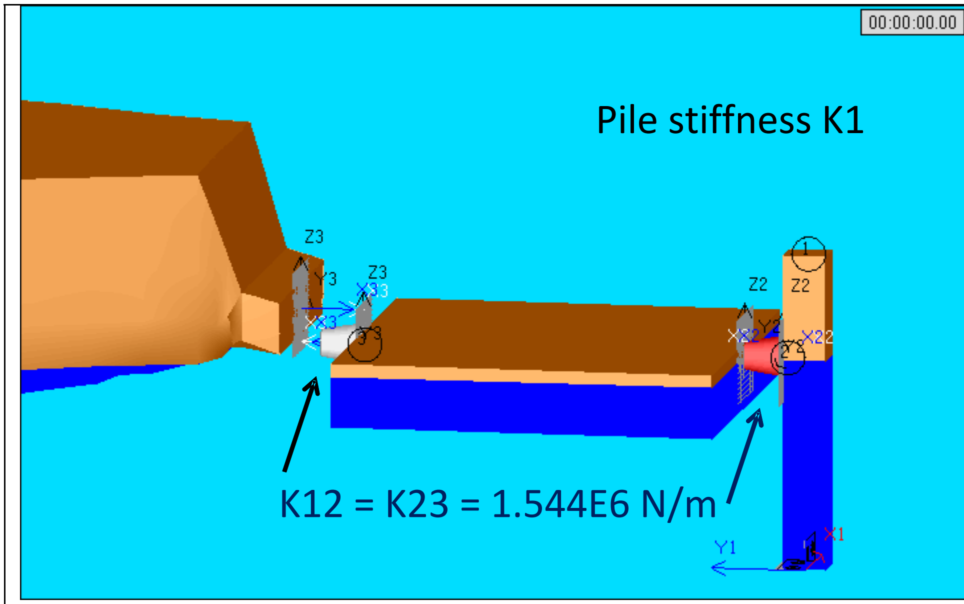


PILE STIFFNESS k1 (E6 N/m)	FENDER STIFFNESS FLOAT TO FERRY k12 (E6 N/m)	Ratio Fender Stiffness/Pile Stiffness	PEAK FENDER FORCE (E6 N) F23 For d=0.8kts KE=0.75E6 J	PEAK PILE FORCE (E6 N) F1 For d=0.8kts KE=0.75E6 J	SAMPLE FILE FOR M/V KENNICOTT
99999.0	0.515	0.00	0.916	0.916	AD311XfG.dat
1.55	0.775	0.50	0.950	0.752	AD311XfO.dat
1.030	1.030	1.00	1.044	0.772	AD311XfK.dat
0.78	1.550	2.00	1.153	0.794	AD311XfP.dat
0.60	3.650	6.08	1.462	0.783	AD311XfQ.dat
0.55	8.000	14.55	2.015	0.762	AD311XfR.dat

Figure 30. Effect of Relative Stiffness for Cases of the Float F1 Hinged to Pile P1

5.4 PILE STIFFNESS EFFECTS

In this SERIES-4 we specifically vary the pile stiffness K1 while holding other parameters steady with KENNICOTT berthing in the surge direction. Figure 31 summarizes the conditions modeled and ferry berthing speeds of ‘a’ through ‘f’ were run for each pile stiffness shown in Figure 30 and results tabulated.

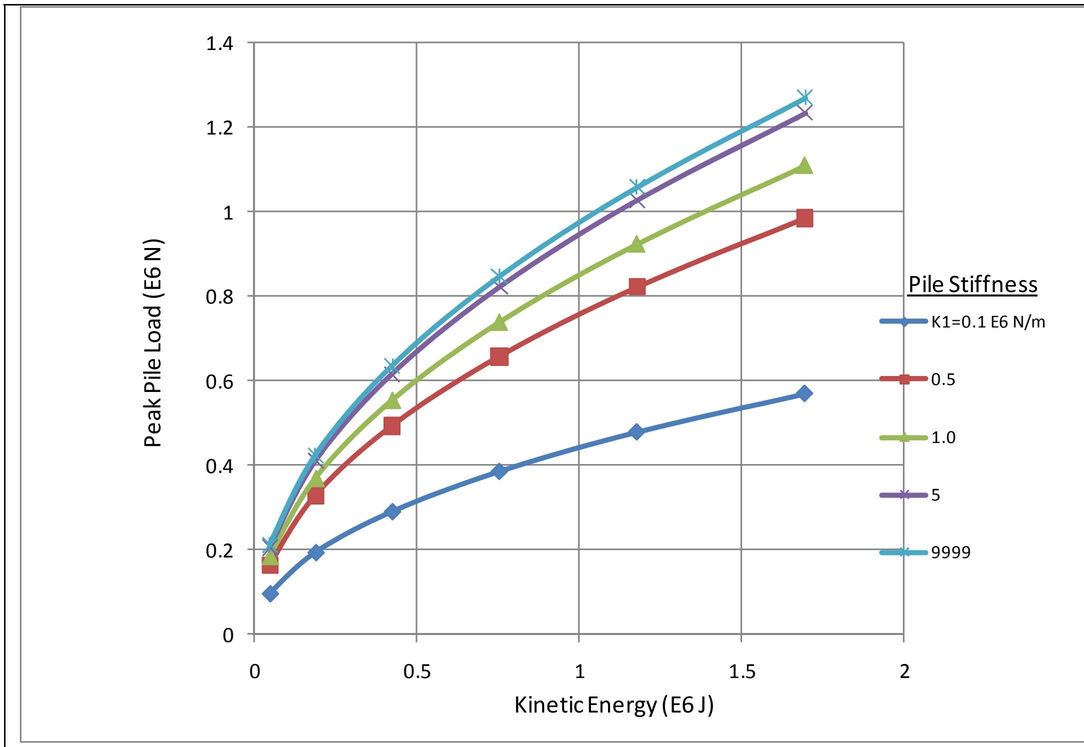


SERIES-4

SAMPLE FILE	*SERIES*	*PILE STIFFNESS K1 (E6 N/m)*
AD311XfU.dat	U	0.1
AD311XfV.dat	V	0.5
AD311XfA.dat	A	1
AD311XfW.dat	W	5
AD311XfX.dat	X	9999

Figure 31. SERIES-4 Modeling

Figure 32 shows the peak loads on the top 'spring' holding the pile. The upper portion of Figure 32 shows peak pile load as a function of in-coming ship total kinetic energy for various values of pile stiffness. The lower portion of Figure 32 illustrate that there is an approximately linear inverse relation between pile deflection and peak load. The more a pile is allowed to move then the lower the peak load for a given total ship kinetic energy. Figure 33 shows sample details for simulation AD311XdV.dat.



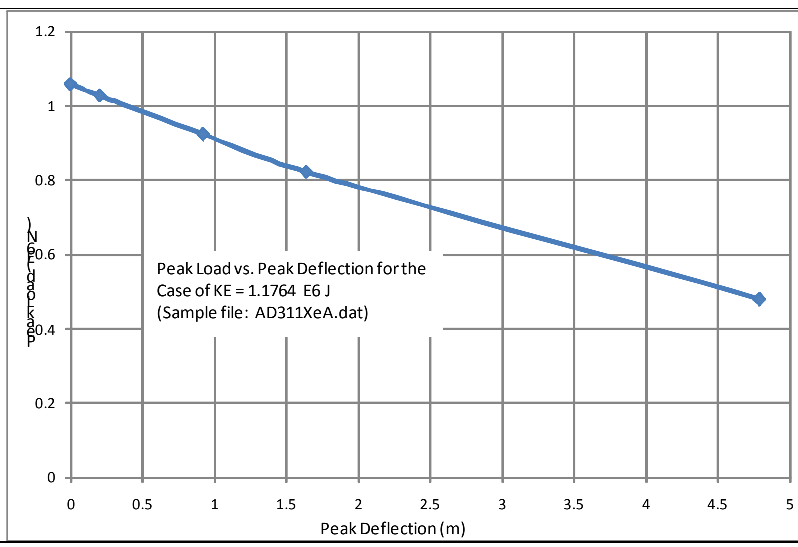


Figure 32. SERIES-4 Modeling Results

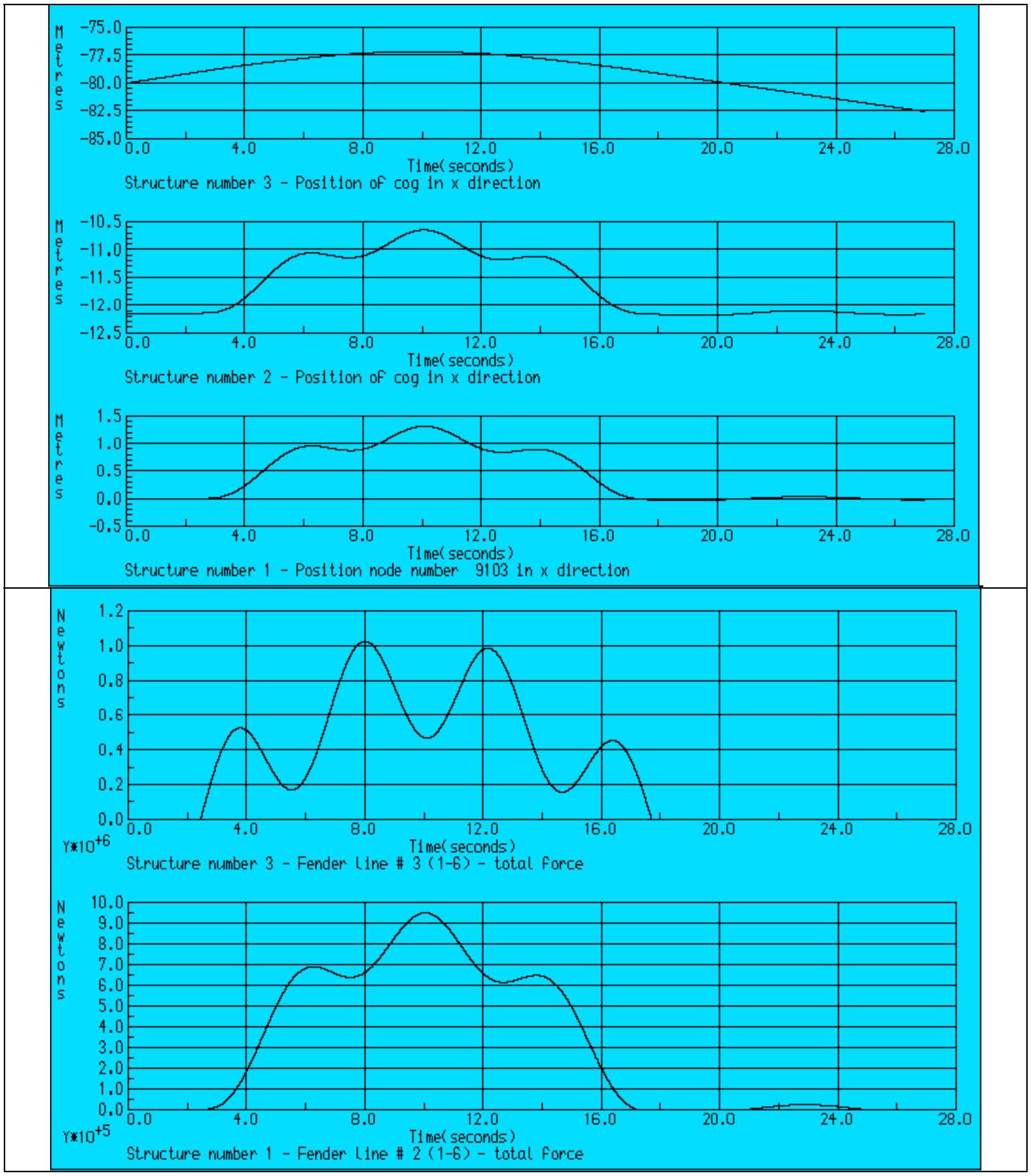


Figure 33. Sample Details for Simulation AD311XdV (KENICOTT in-coming surge speed of 0.4118 m/s and Pile top line stiffness of 0.5 E6 N/m)

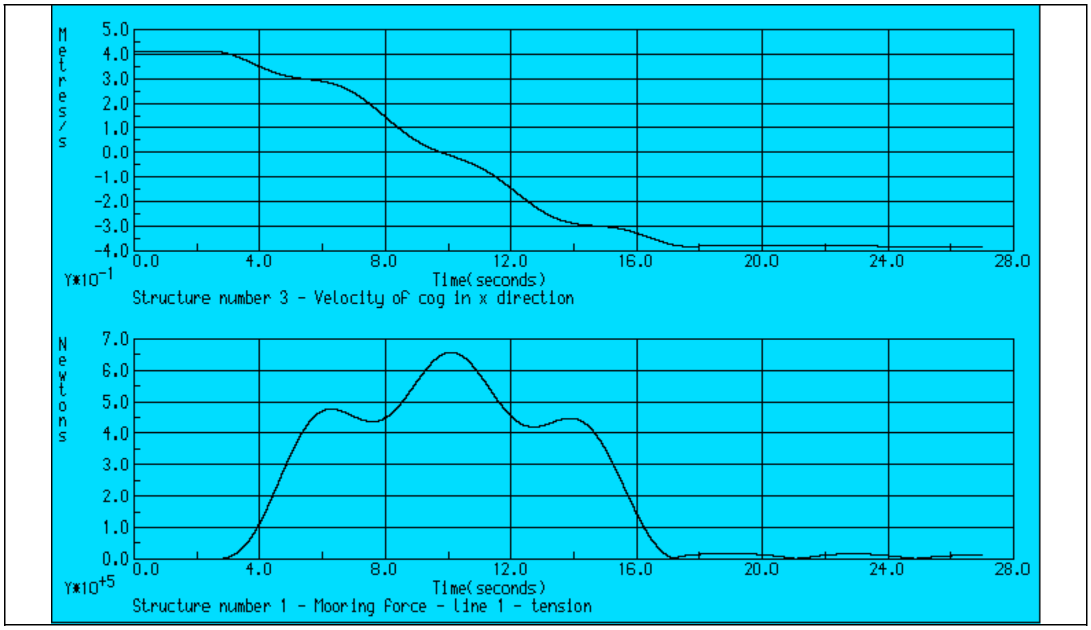


Figure 33 cont. Sample Details for Simulation AD311XdV (KENICOTT in-coming surge speed of 0.4118 m/s and Pile top line stiffness of 0.5 E6 N/m)

5.5 WAVE EFFECTS ON THE CONCRETE FLOAT

In SERIES-5 the concrete float "F1" is held with 3 piles in an asymmetric arrangement, as shown in Figure 34. At the top and bottom float deck there are 3 fenders bearing on each pile (i.e. 6 fenders per pile; fenders shown in red; and three piles). Each fender has a stiffness of K=10,000 N/m.

Two different regular wave conditions were run at this float to determine how the moored float system moves in monochromic waves. In file AN1A.dat waves with H=1.0m and =3.2 sec were run at 0 degrees (i.e. the wave crests were parallel to the left face of the float) and Figure 35 shows float motion results. File AN3B.dat used H=2.0m and T=4.0 sec waves at 30 degrees and Figure 36 shows float motion results. Note that the waves were allowed to "ramp-up" in these simulations to reduce numerical start-up effects. Also note that there are some asymmetry effects showing up in the results due to the pile number and locations. For the 2m wave height case the waves tend to go over the deck, as shown in the continuation portion of Figure 36.

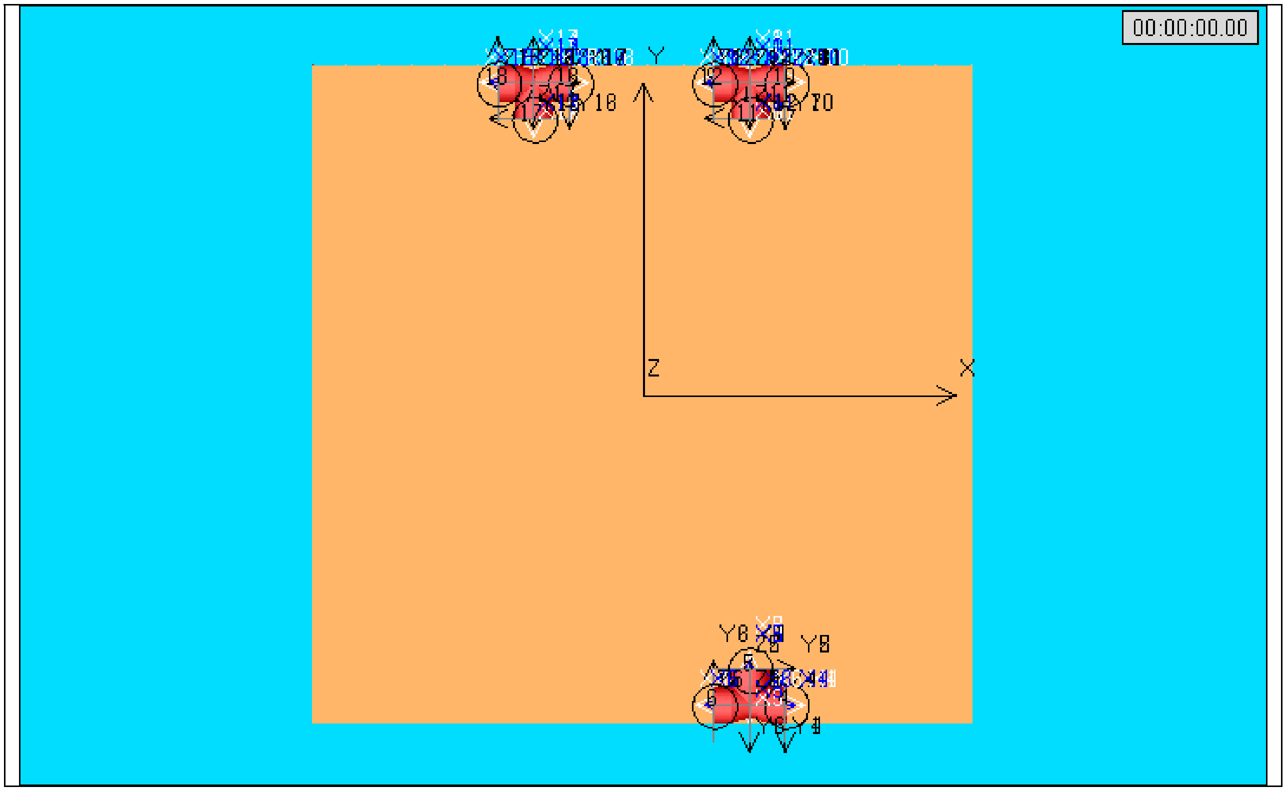


Figure 34. Concrete Float Model with Three Piles and Six Fenders per Pile (3 fenders at the top level of the float per pile and 3 additional fenders at the bottom level of the float; piles not shown for clarity)

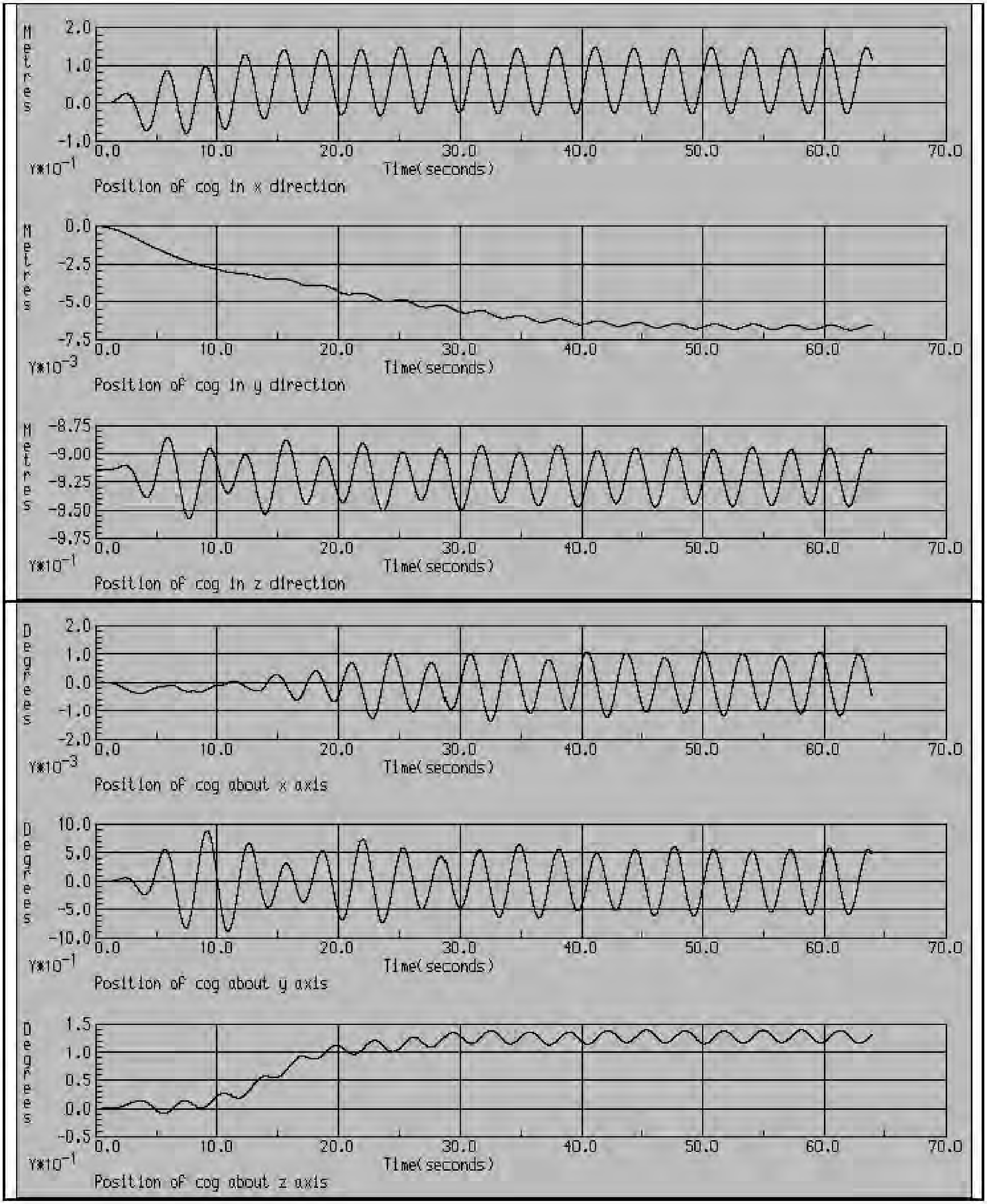


Figure 35. Concrete Float Motion Results for H=1m T=3.2 sec @ 0 deg (AN1A.dat)

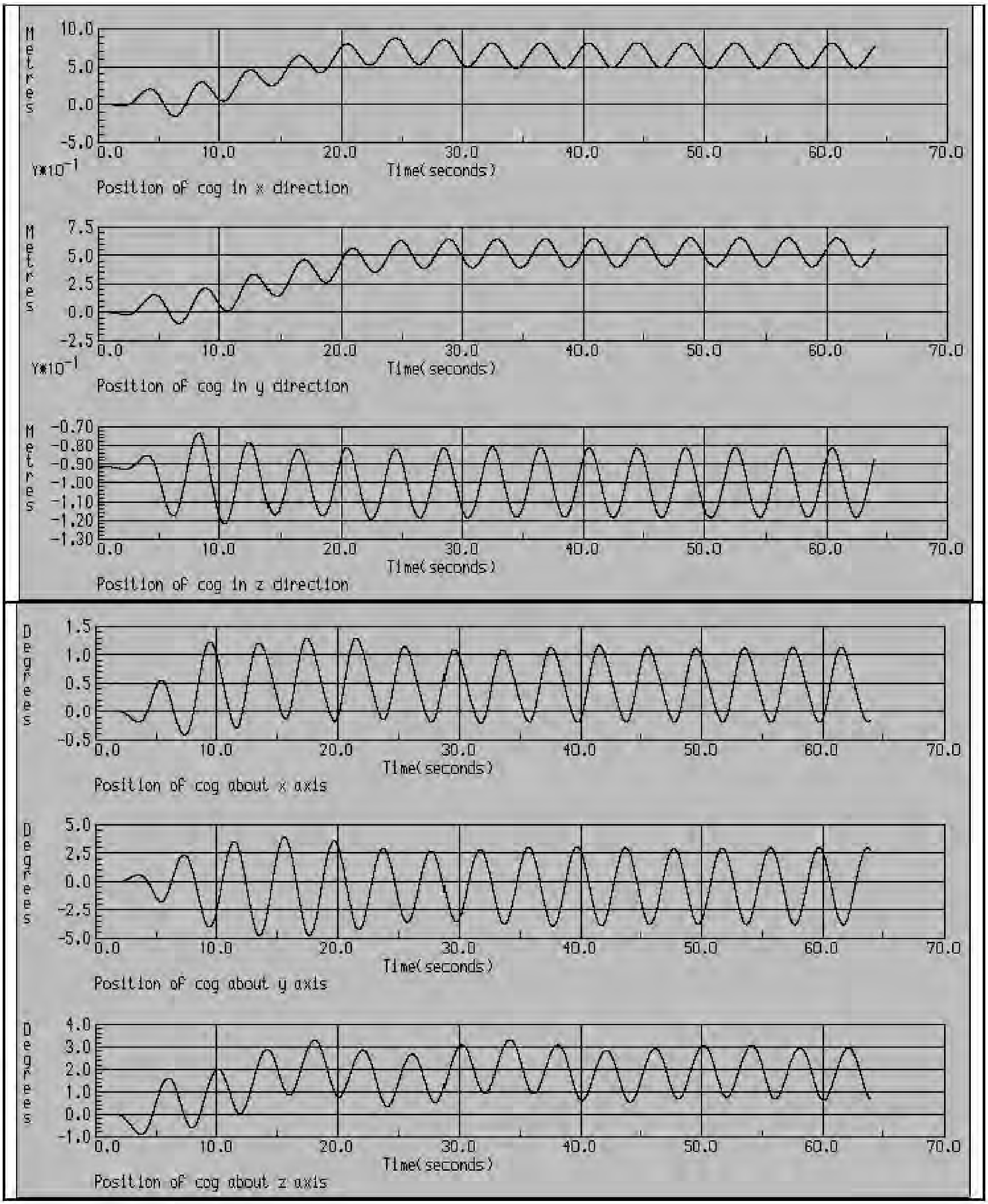


Figure 36. Concrete Float Motion Results for H=2m T=4.0 sec @ 30 deg (AN3B.dat)

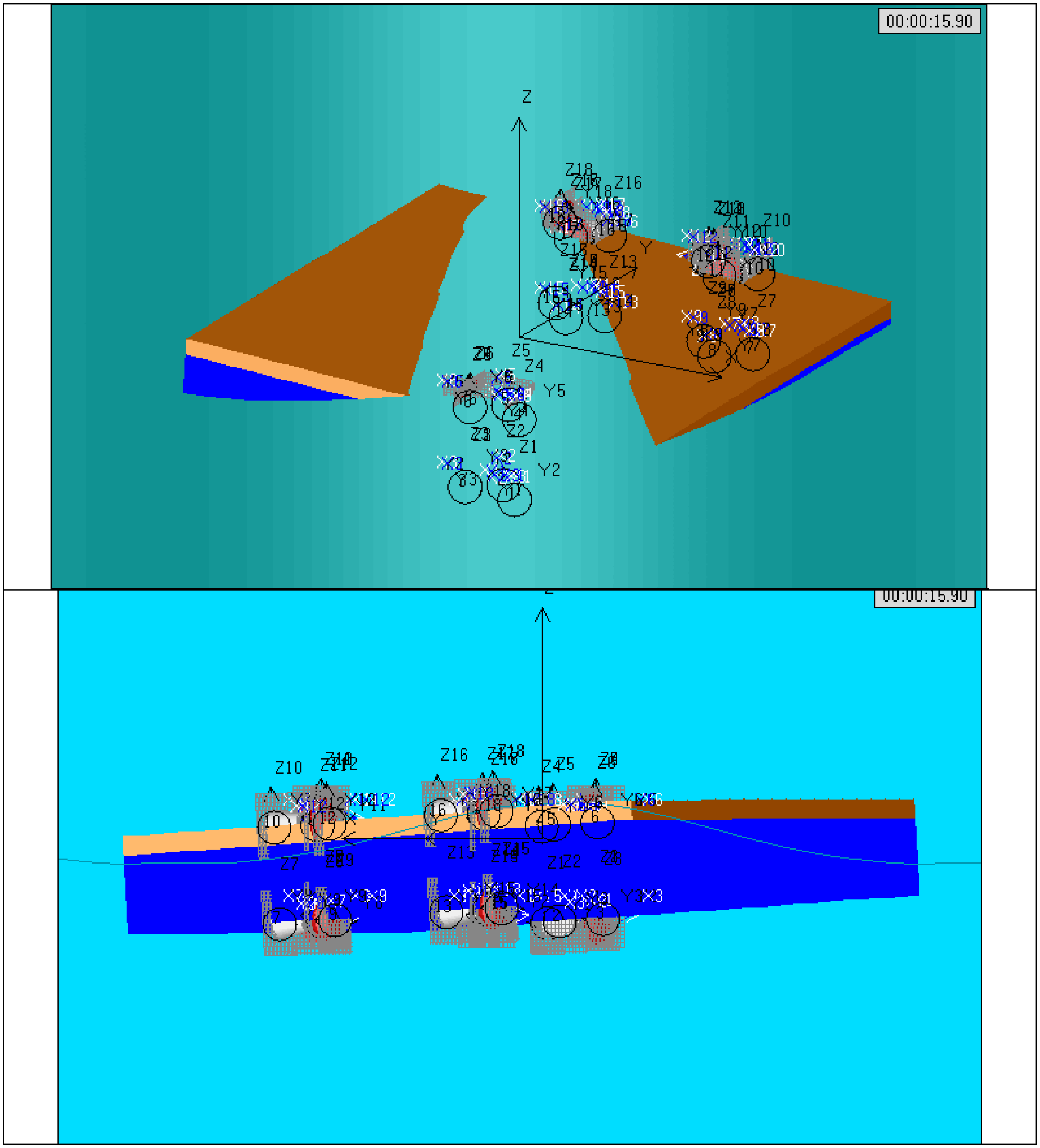


Figure 36 cont. Concrete Float Motion Results for H=2m T=4.0 sec @ 30 deg (AN3B.dat)

5.6 KENNICOTT BERTHING AT THE CONCRETE FLOAT WITH 3 PILES

In SERIES-6 KENNICOTT berths longitudinally in the middle of the concrete float “F1” with the float held with 3 piles and associated fenders, as shown in Figure 37. In simulation ADKENF1.dat each of the fenders between the piles and float have a stiffness of 2.5E5 N/m each, while the fender between float and ship has a stiffness of 1.544E6 N/m. In this simulation the initial incoming ship speed is 0.4118 m/s. Figure 38 shows the results of this dynamic simulation.

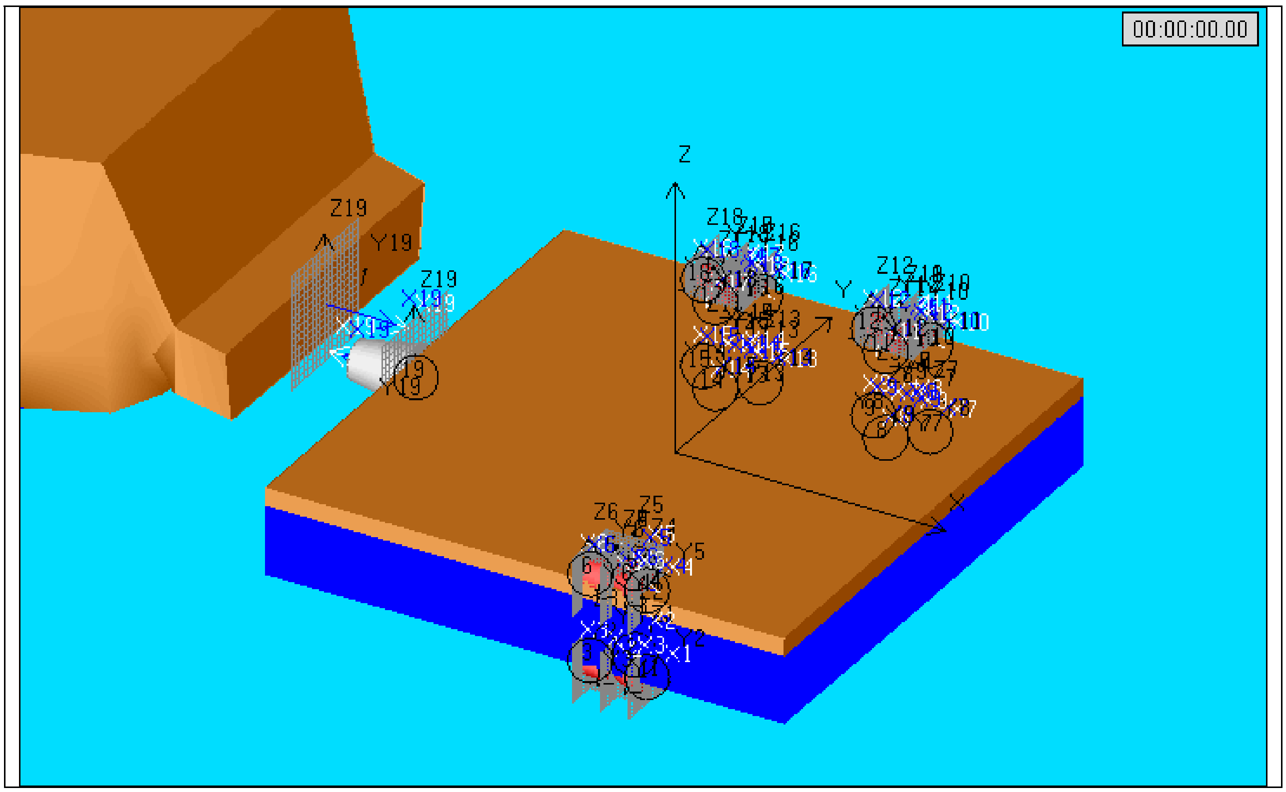


Figure 37. KENNICOTT BERTHING AT CONCRETE FLOAT (ADKENF1.dat)

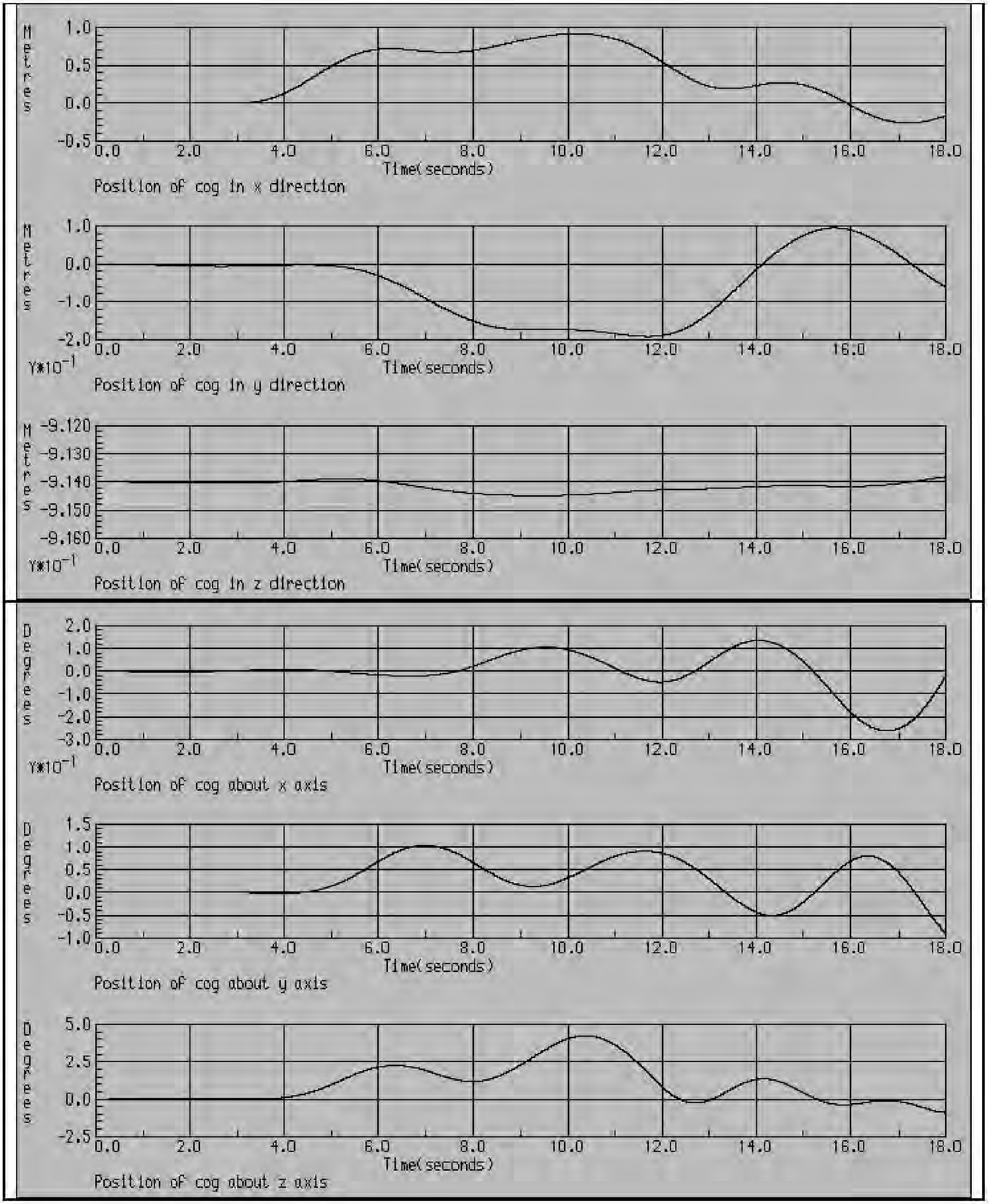


Figure 38. KENNICOTT BERTHING AT CONCRETE FLOAT (ADKENF1.dat)

SUMMARY AND CONCLUSIONS

Various dynamic simulations of ferry berthing were performed and results presented in a systematic form for use in calibrating and developing design/analysis tools. The key conclusions from this study are:

Ferry Effects

It turns out that only key ferry parameter during berthing is the ferry's in-coming kinetic energy that must include the added mass of water moving with the vessel. Simulations were performed for various ferries going in various directions (surge and sway). For a given berthing system the results are the same for a given amount of in-coming kinetic energy no matter which ferry was used nor which direction the ferry took.

All of the Alaska ferries have relatively small surge-surge added masses (Table 4). For lateral berthing the added mass of water is much more important and needs to be included in the kinetic energy calculation. Fortunately, under-keel clearances tend to be large at Alaska ports so in this case the sway added mass of a ferry is a constant for a given hull form and computed values for four classes of Alaska ferry's have been calculated and are provided in Figures 39a and 39b, plotted at two different scales. These in-coming berthing energy calculations include the added masses of water moving with the ship.

Pile / Fender Effects

The overall stiffness of the system, k, in the direction of berthing is found to be a key parameter.

Simulations show that it is best to keep the connection between the float and pile system relatively stiff in the direction of berthing. A soft connection at this point allows the float to pick up momentum and kinetic energy and momentum, which increases peak fender load.

The relative stiffness of the other various components are shown to typically not be important. The exception to this case is for a very unbalanced system where the marine fender is very stiff and a pile system were very soft (however, this is generally the opposite to what actually occurs).

Tide Effects

For a typical Alaska ferry terminal the tide range may be large. However, the tide will not have much of any effect on the ferry and float hydrodynamics because the under-keel clearance is typically large. These effects only start to have a significant effect when the ratio of ship draft to water depth is T/d > 0.5. Therefore, the main influence of a tidal water level change may be on the pile system stiffness. At low tide the effective stiffness of a pile system could be relatively high. While at high tide the piles are effectively longer and therefore may allow for more bending for a somewhat softer system. This pile effect is taken into account in the system stiffness.

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Table 4. Selected Characteristics of Alaska Ferries

SHIP	LENGTH	WIDTH	DRAFT	IN-AIR	FOR DEEP WATER	
	L (m)	B (m)	T (m)	MASS, M (E6 kg)	Cm Surge	Cm Sway
Fast Vehicle Ferry FVF	72.200	13.260	2.420	0.704	1.038	2.423
M/V AURORA	64.000	16.764	3.886	1.348	1.106	1.710
M/V KENNICOTT	115.230	25.880	4.870	8.881	1.121	1.840
M/V TAKU	106.200	22.560	4.570	3.535	1.095	1.760

Note: Cm = 1 + Ma/M; where M=ship mass in-air and Ma = added mass of water.
Therefore, total berthing mass = Cm*M

The values for Cm in the table above are for the case of deepwater where the ratio of ship draft to water depth is T/d <~ 0.3 ; for shallow water Cm increases and NAVFAC ESC Report TR-6074-OCN of 2010 can be used to determine shallow water values of Cm.

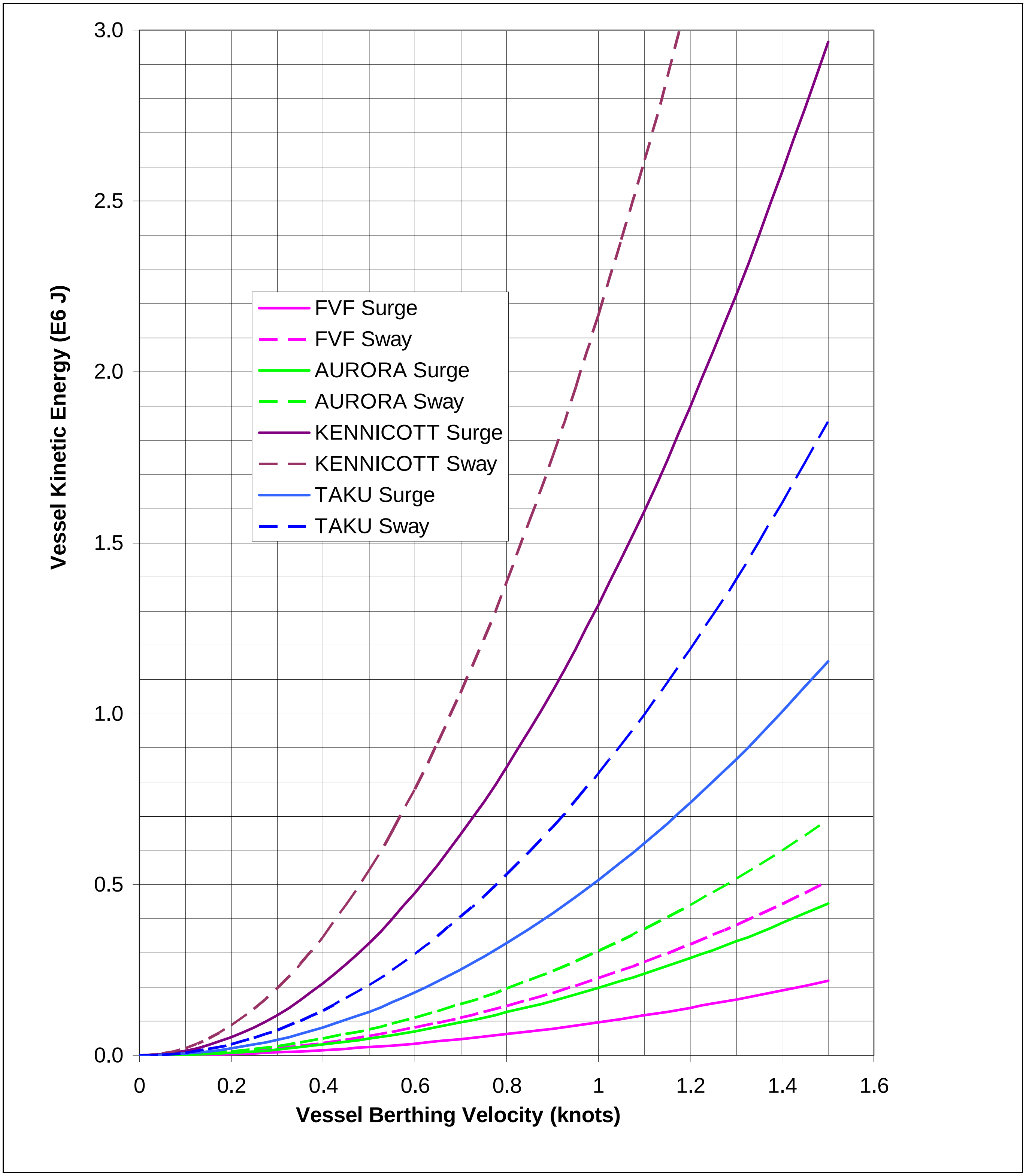


Figure 39a. Kinetic Energies of Alaska Ferries

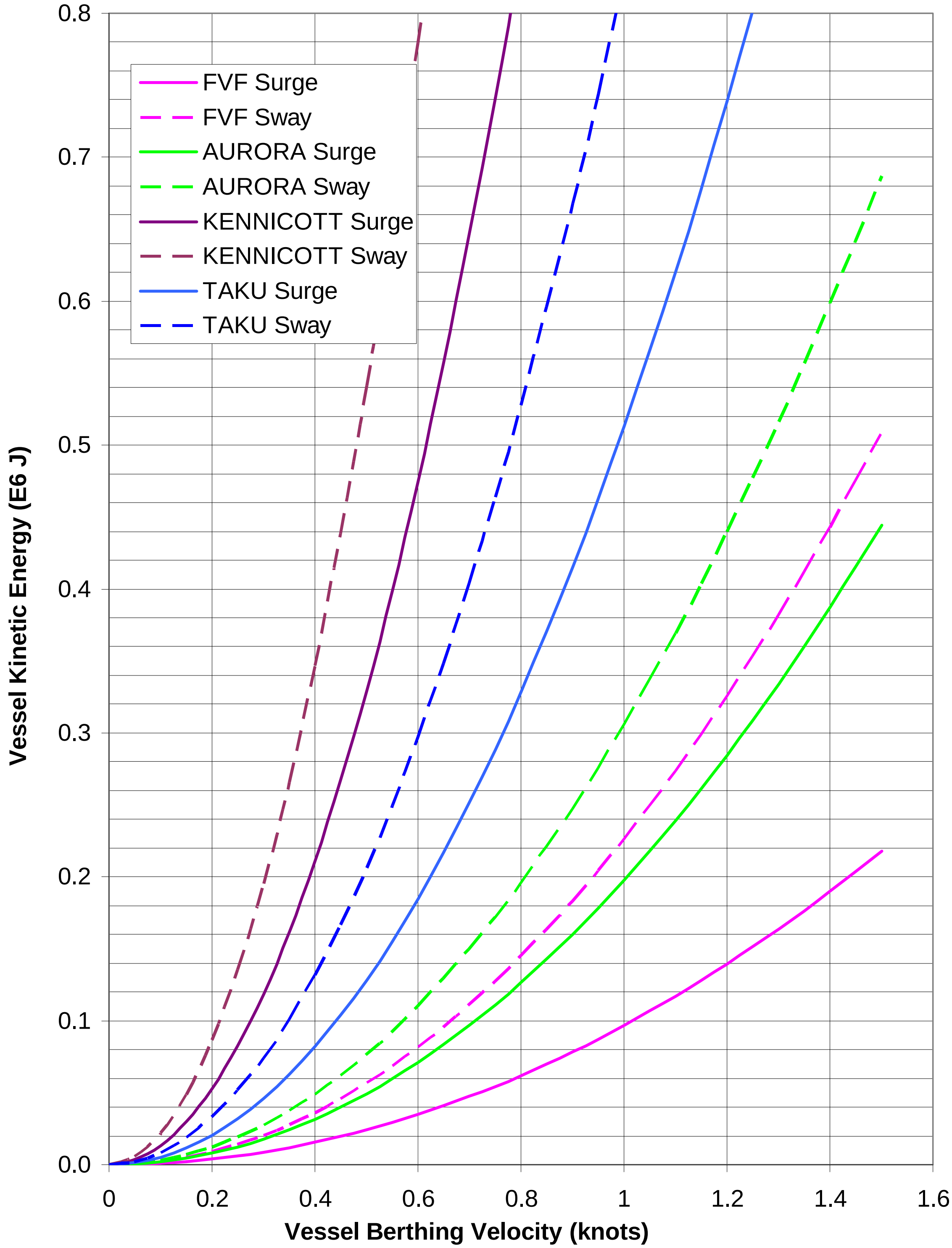


Figure 39b. Kinetic Energies of Alaska Ferries

Annex B

Vessel Impact (SDOF)

Results for One Dimensional Analysis

The responses of the piling system in one dimensional analysis are numerically calculated given the mass of the vessel and the float, the stiffness of the fender and the stiffness of the piling system fixed on the float. In the analysis, the ratio of the mass of the vessel to the float is chosen from 0.1 to 100. The mass of the vessel varies from 800LT to 10,000LT for a certain mass ratio between the vessel and the float. The stiffness of the fender is chosen as 10kips/in, the stiffness of a single pile ranges from 10kips/in to 1000kips/in, therefore the stiffness of the piling system that consists of three piles ranges from 30kips/in to 3000kips/in. In the diagrams given below, the x-axis is chosen as the stiffness of each single pile of the piling system, and the responses on the y-axis are for the single piles as well. The damping ratios are chosen from 2% to 20% of critical damping. In comparison with KEM, the corresponding responses calculated by KEM will be shown on the plots as well.

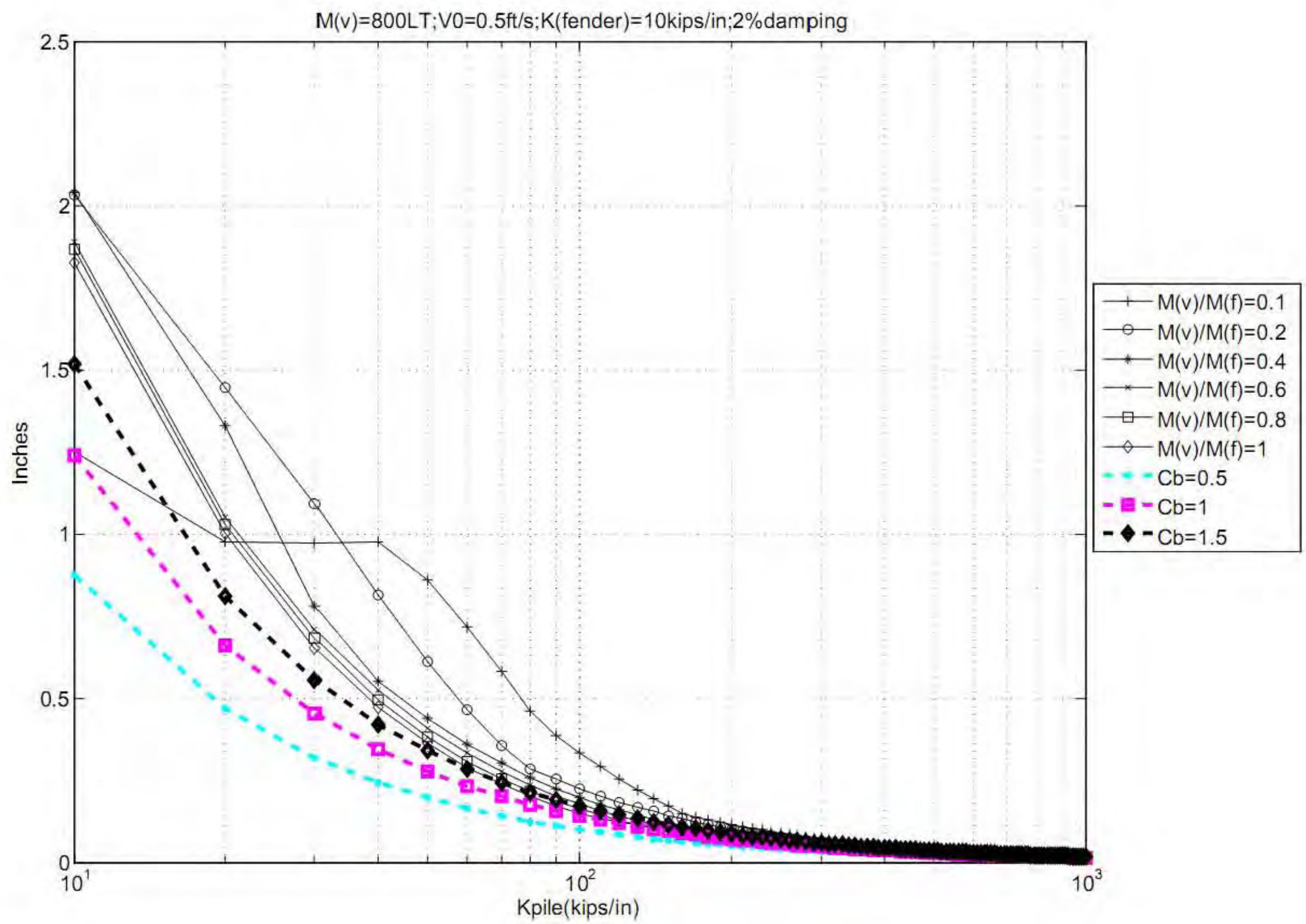
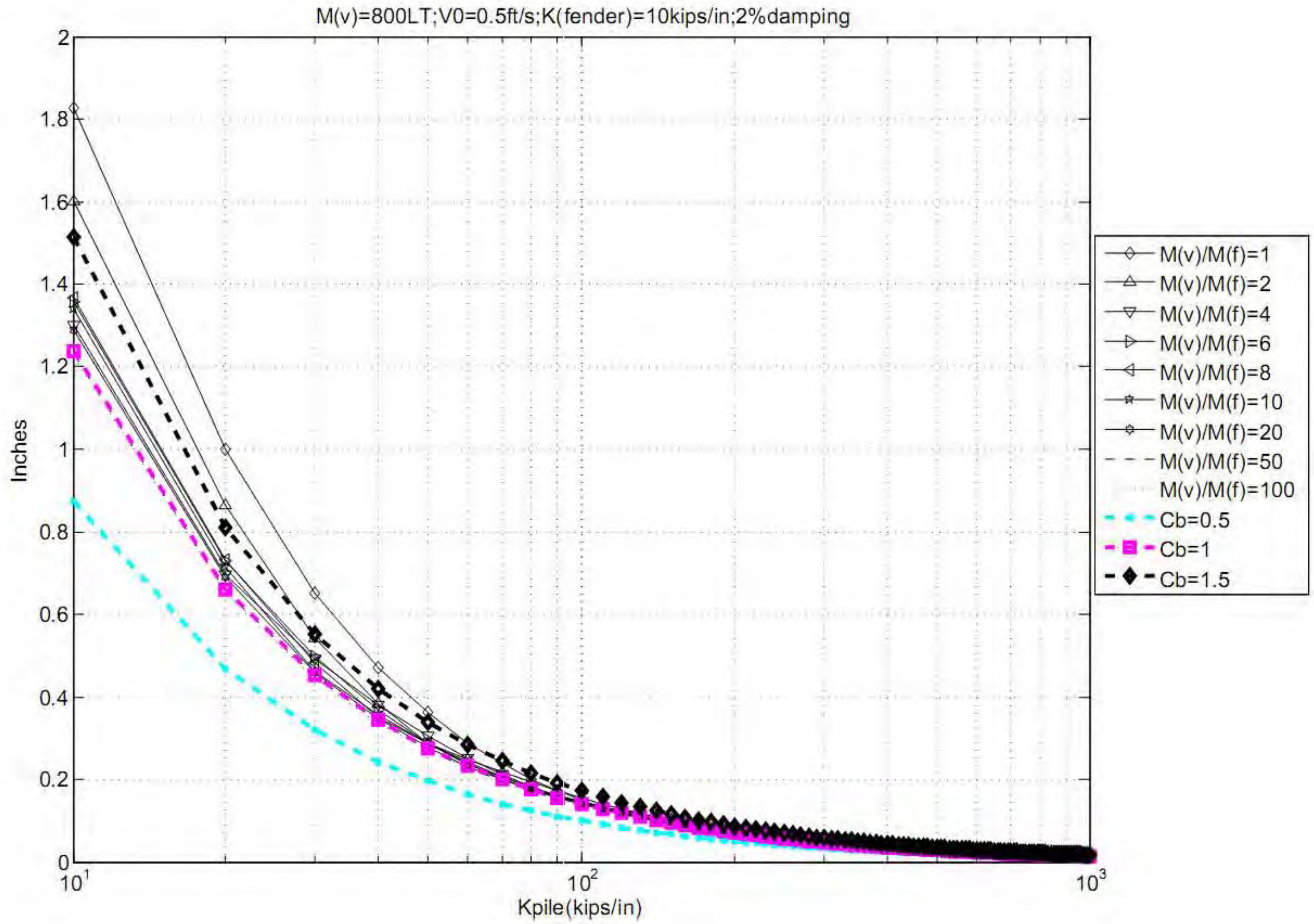
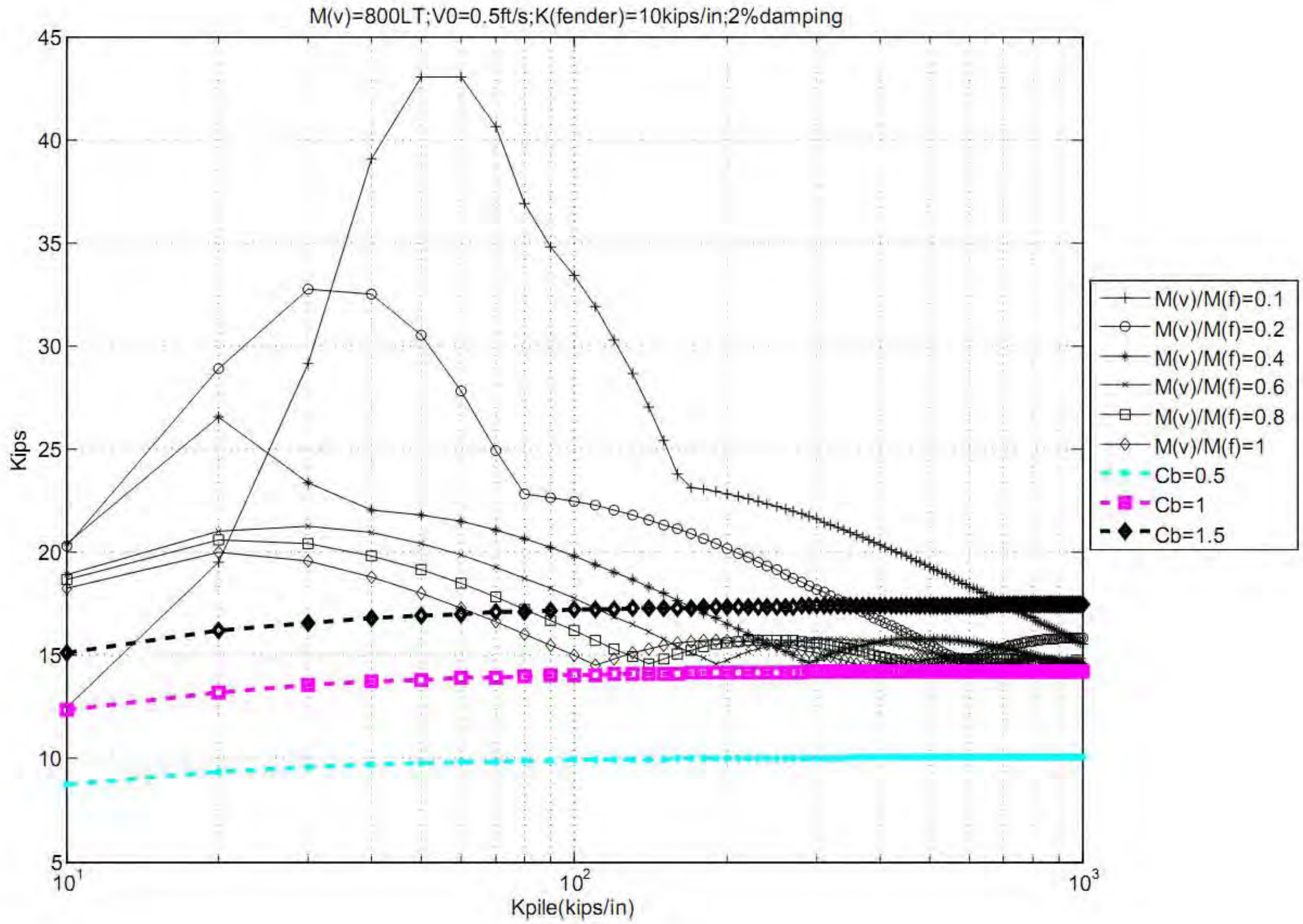

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.1 Displacement of the Piling System 1D-1a



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.2 Displacement of the Piling System 1D-1b



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.3 Reaction Force of the Piling System 1D-1a

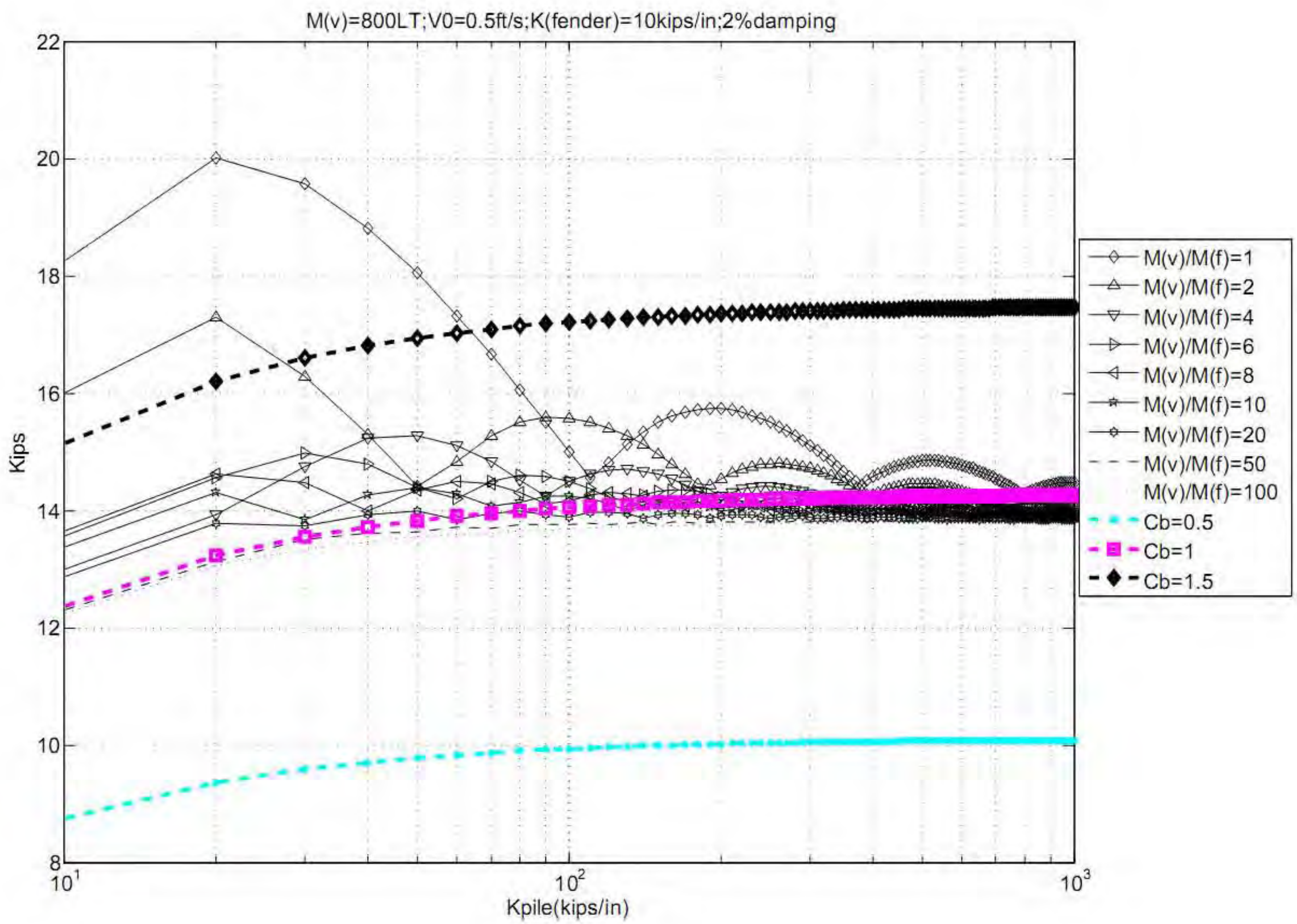

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
22
20
18
16
14
12
10
8
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.4 Reaction Force of the Piling System 1D-1b

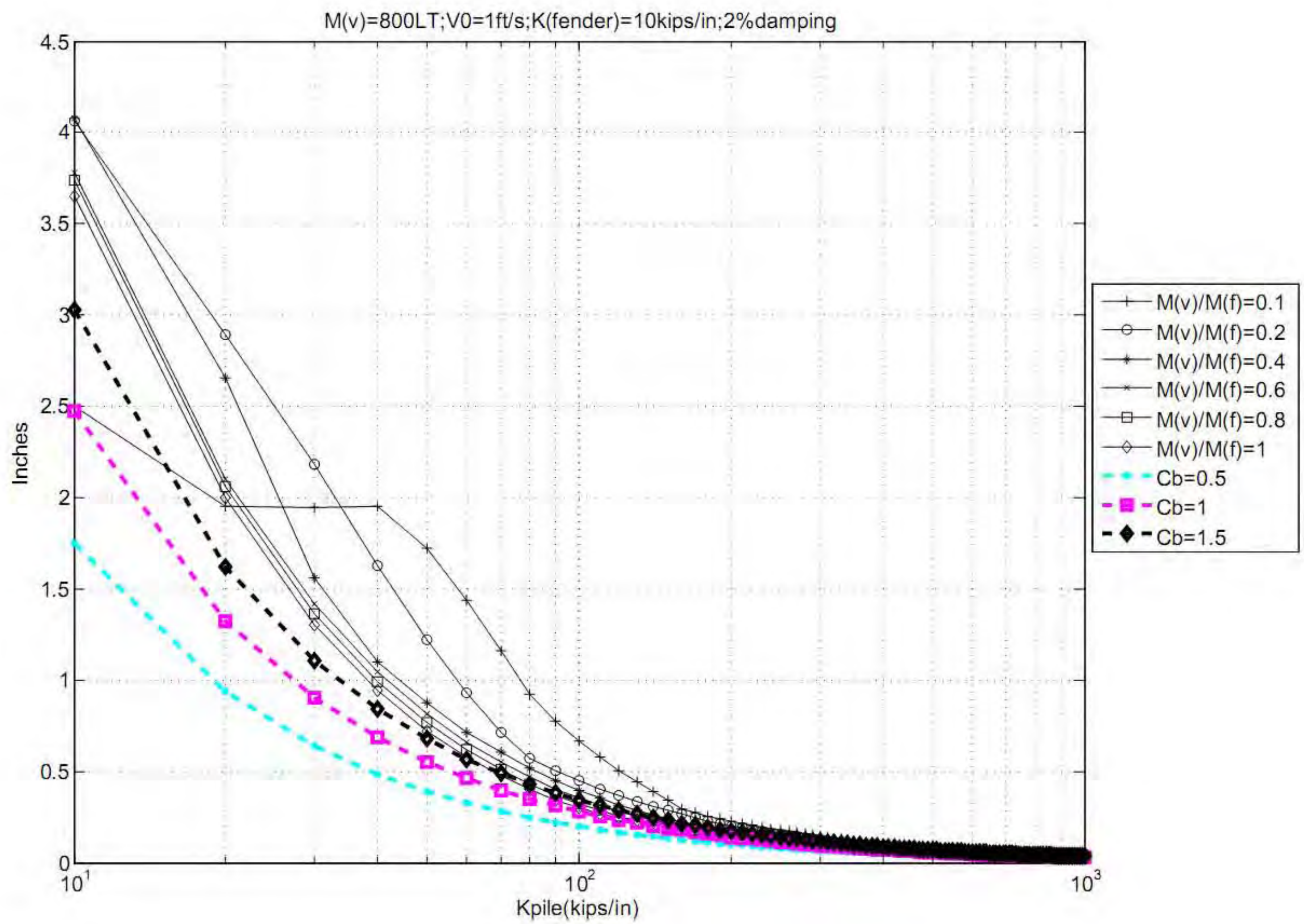

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.5 Displacement of the Piling System 1D-2a

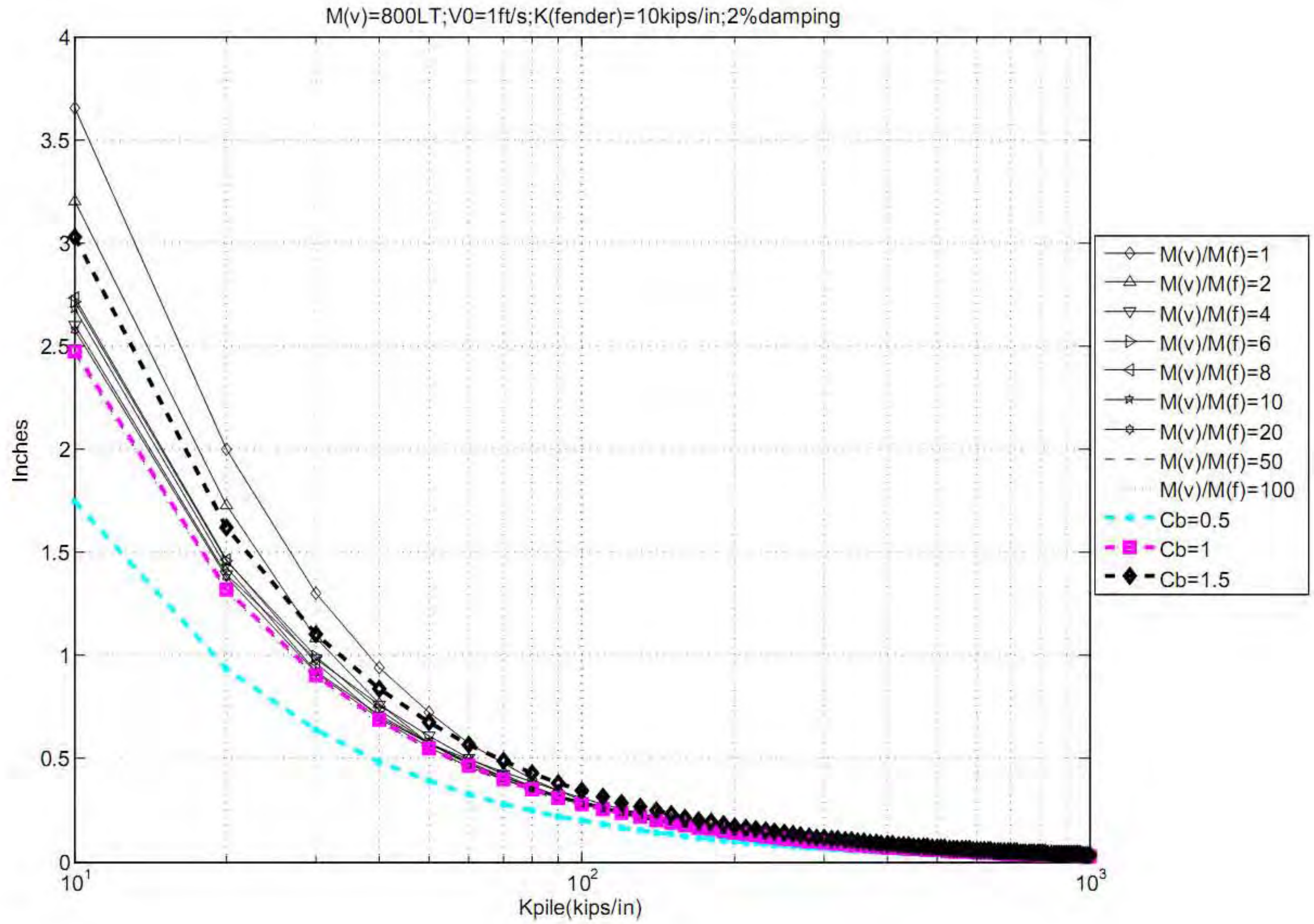

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
0
0.5
1
1.5
2
2.5
3
3.5
4
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.6 Displacement of the Piling System 1D-2a

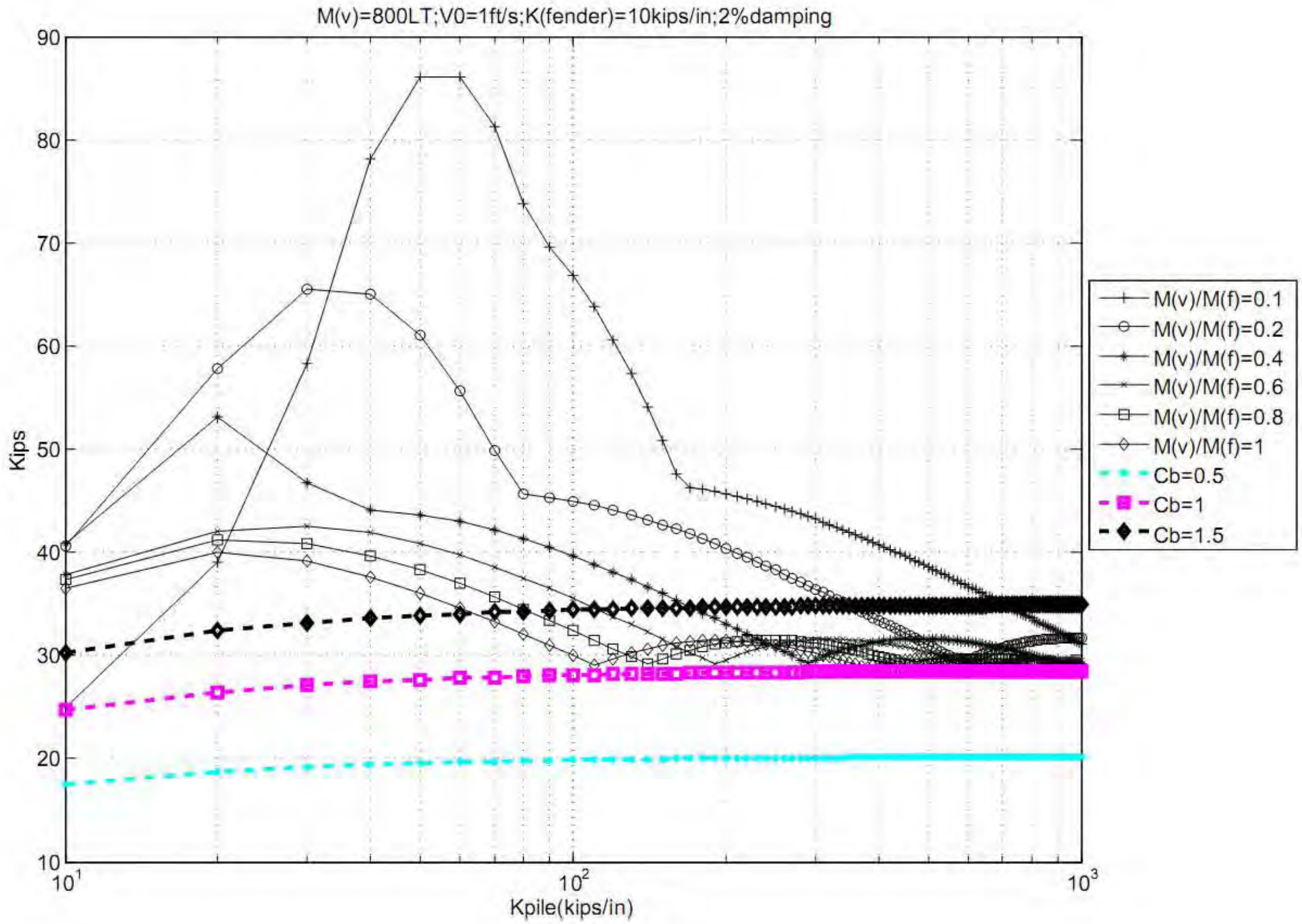
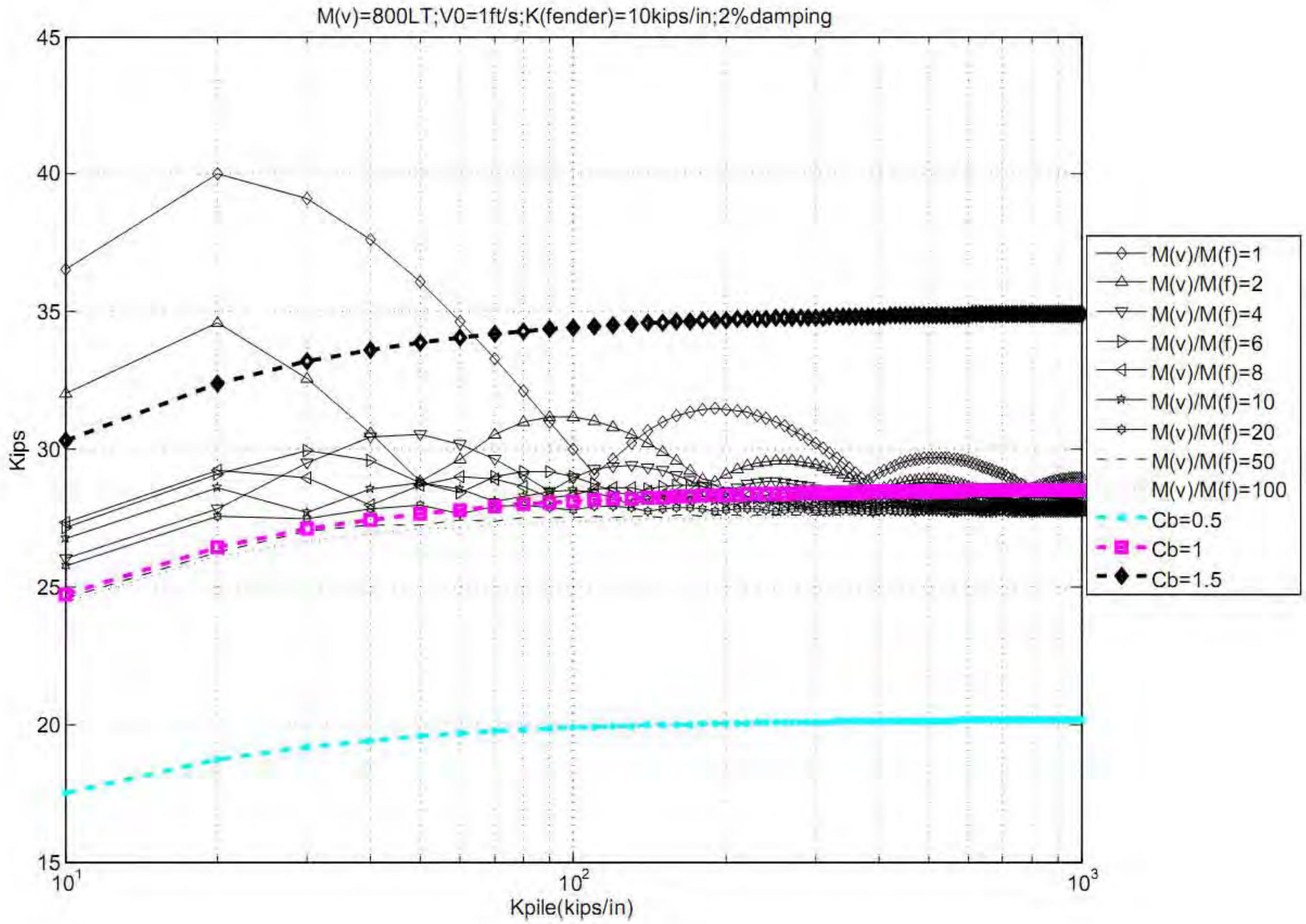
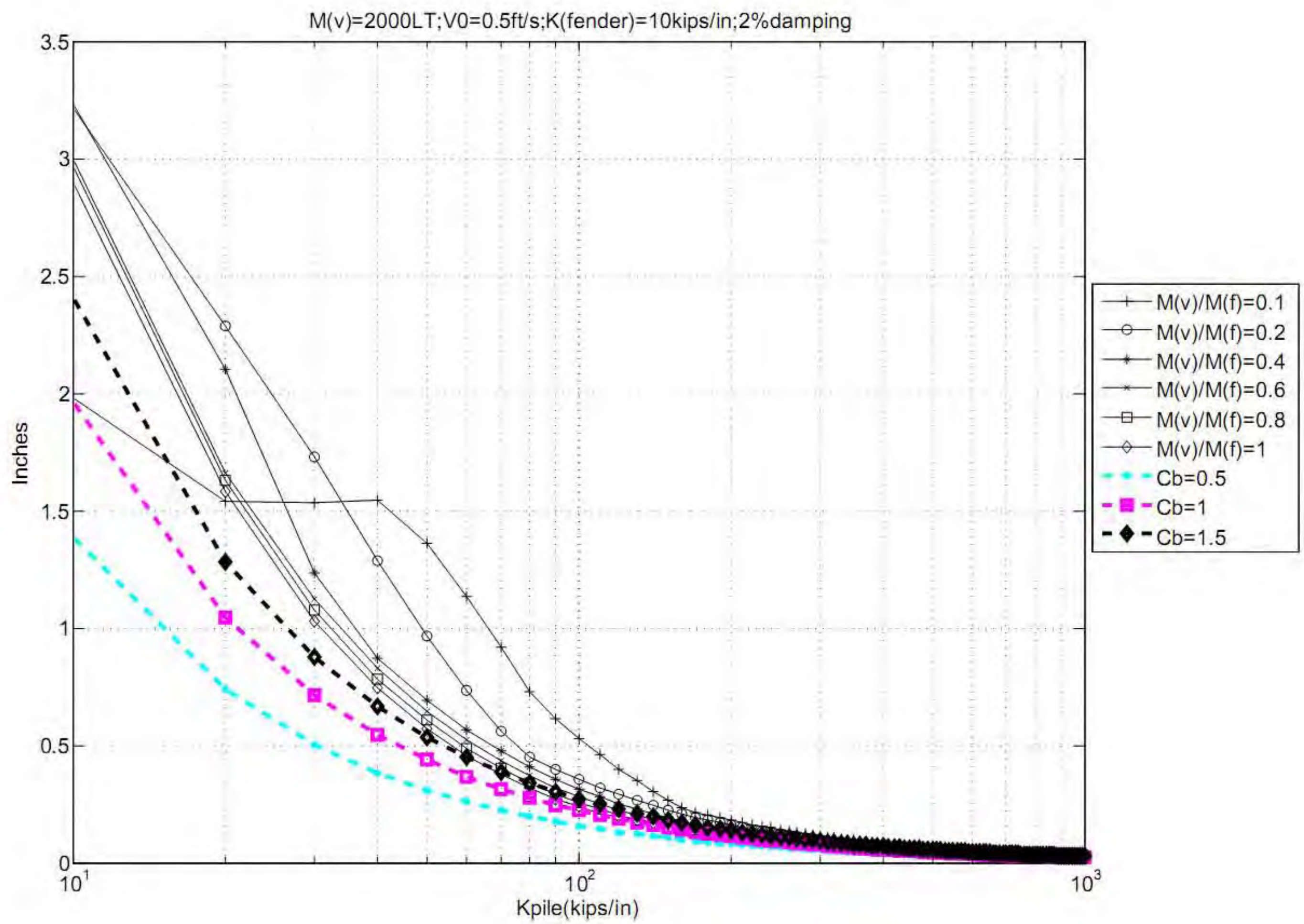

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
90
80
70
60
50
40
30
20
10
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.7 Displacement of the Piling System 1D-2b



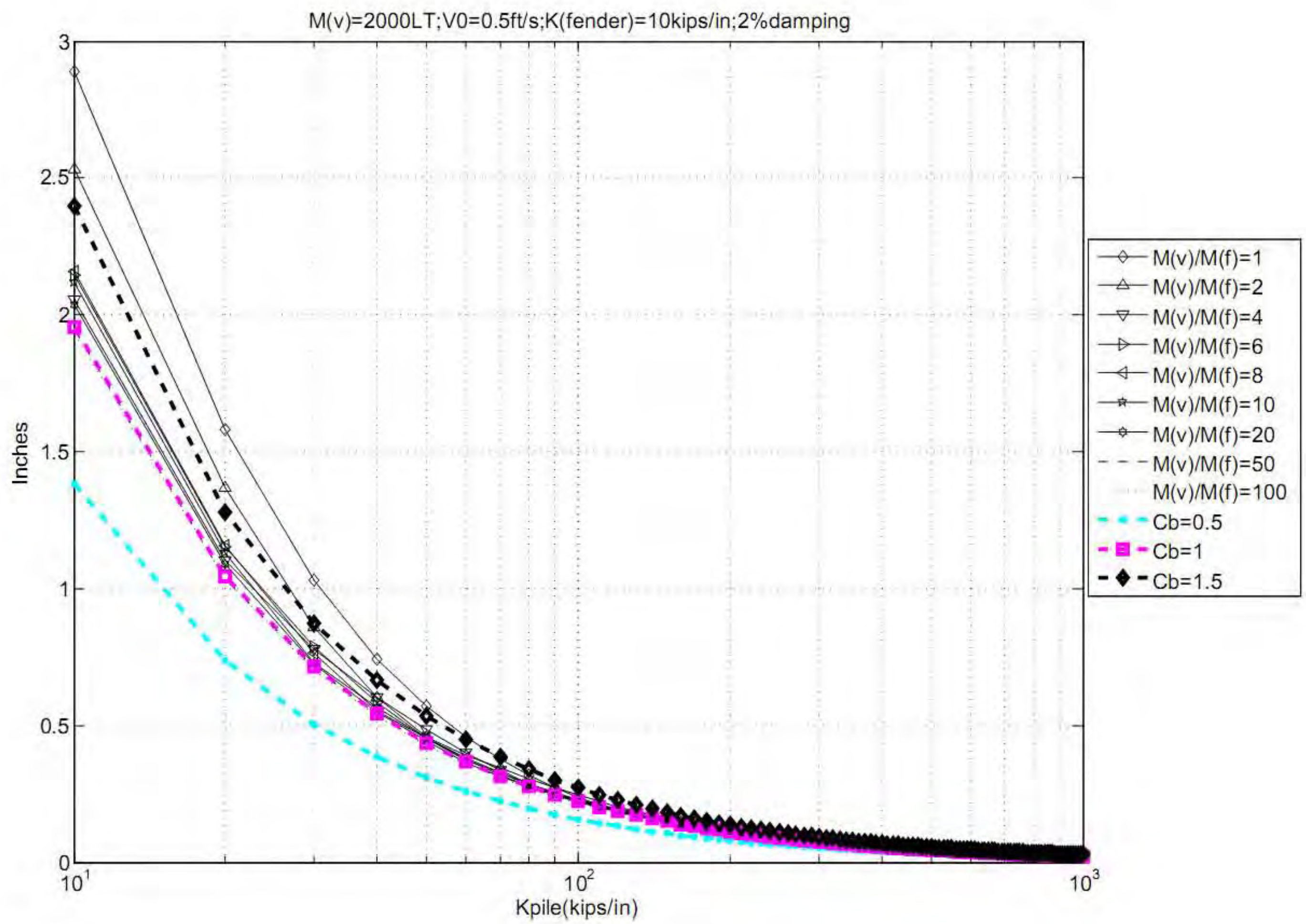
M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
45
40
35
30
25
20
15
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.8 Reaction Force of the Piling System 1D-2b



M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
3.5
3
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.9 Displacement of the Piling System 1D-3a



M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.10 Displacement of the Piling System 1D-3b

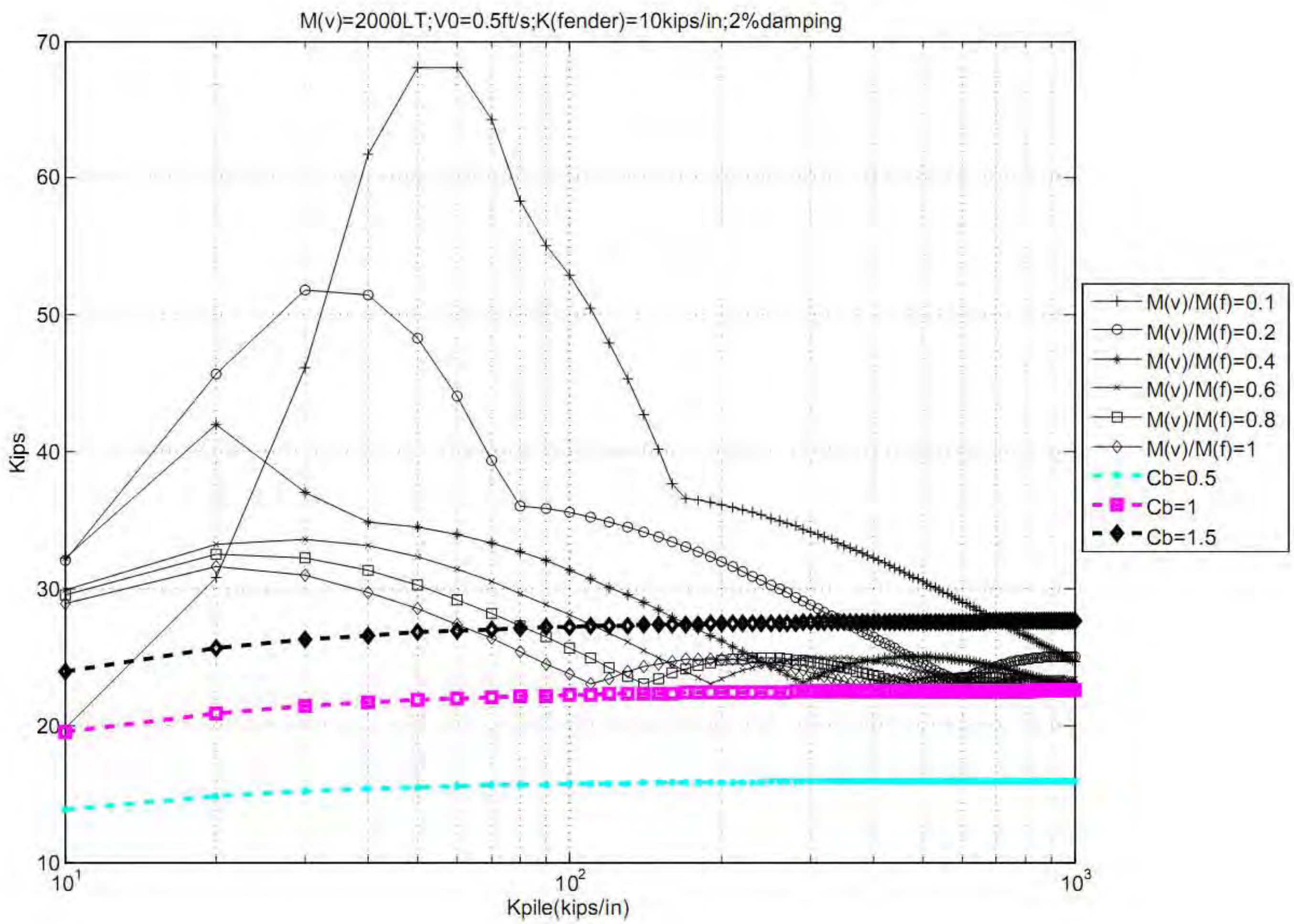

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
70
60
50
40
30
20
10
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.11 Reaction Force of the Piling System 1D-3a

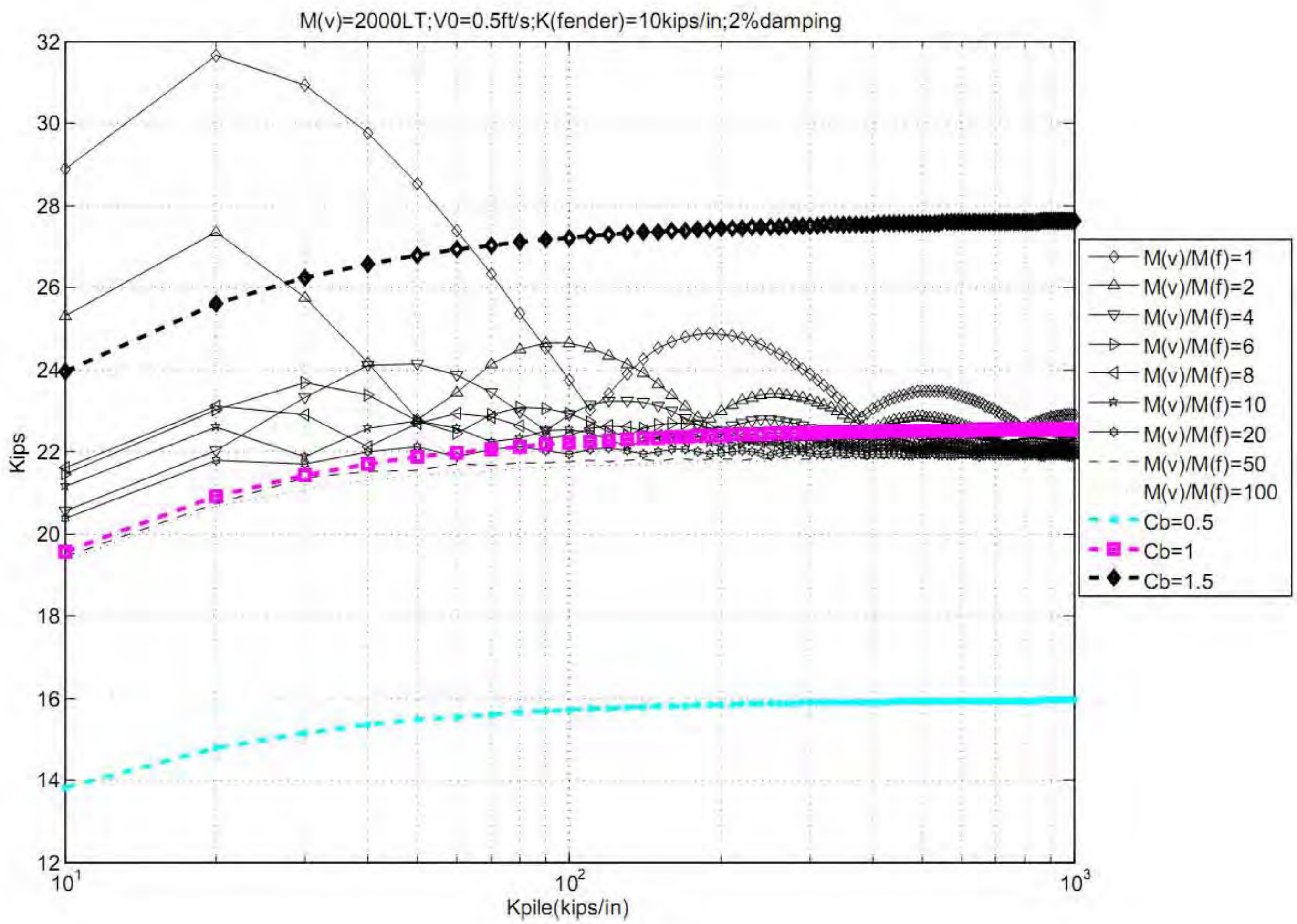
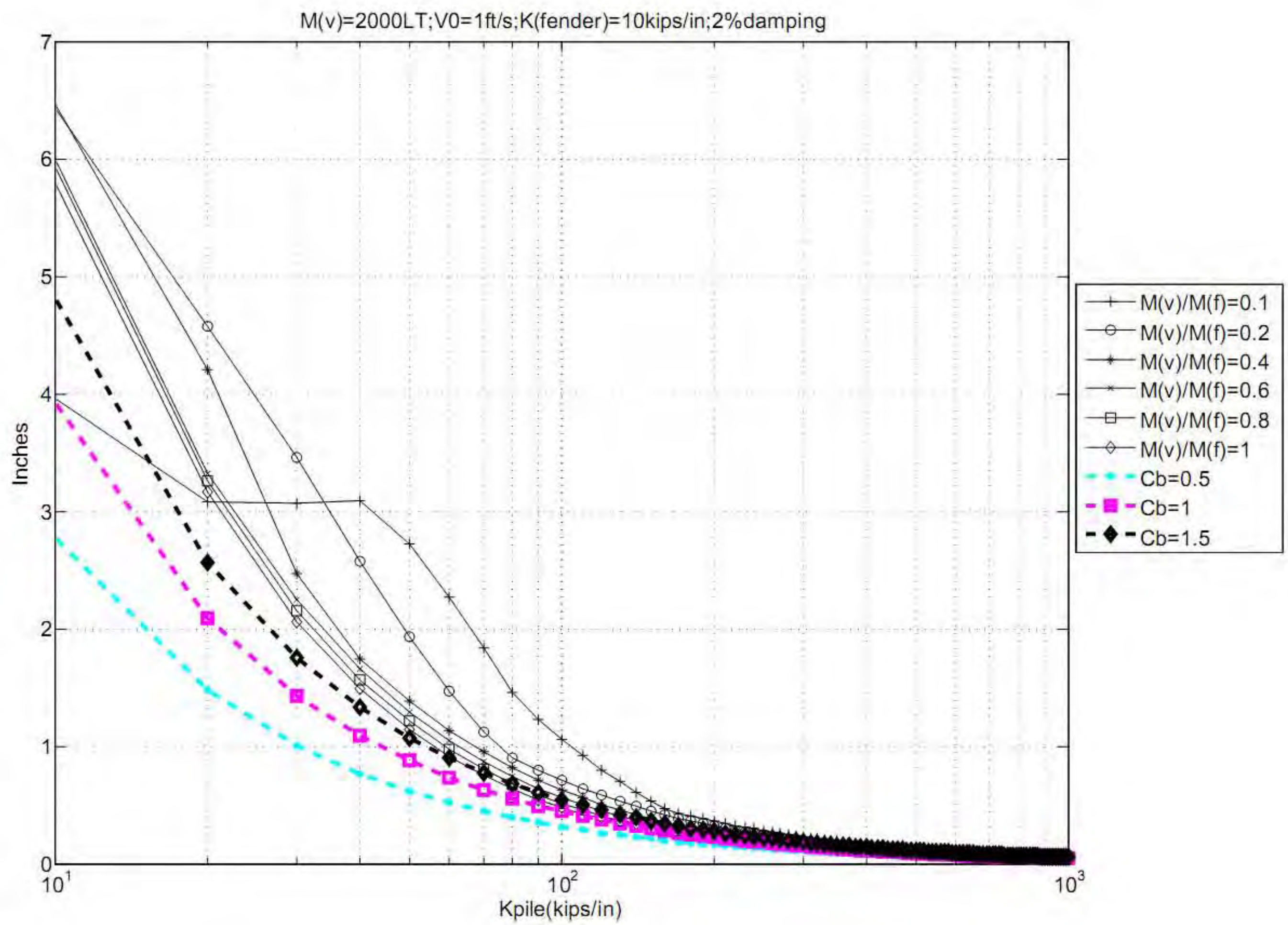
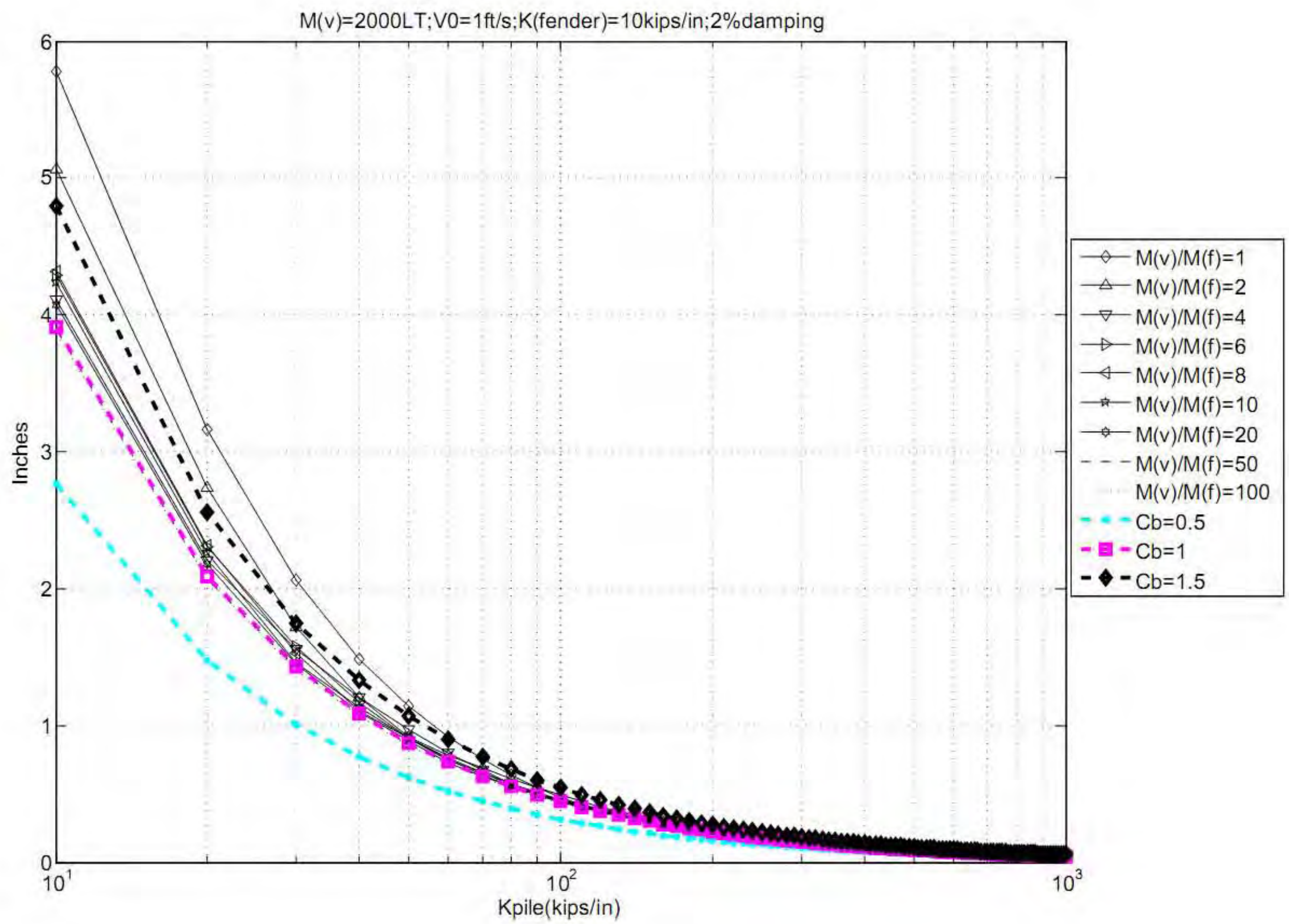

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
32
30
28
26
24
22
20
18
16
14
12
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.12 Reaction Force of the Piling System 1D-3b



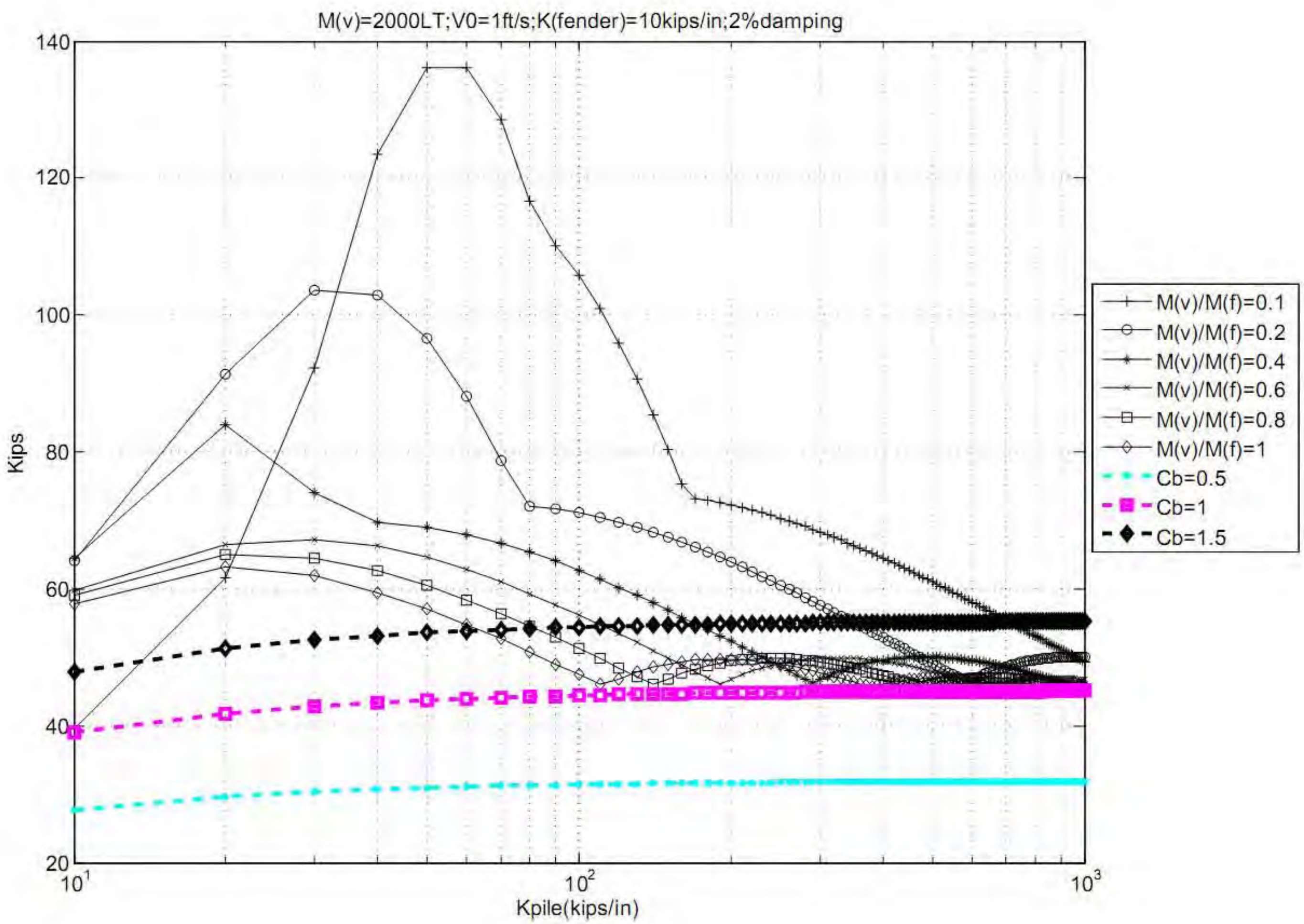
M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.13 Displacement of the Piling System 1D-4a



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
0
1
2
3
4
5
6
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.14 Displacement of the Piling System 1D-4b



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
140
120
100
80
60
40
20
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.15 Reaction Force of the Piling System 1D-4a

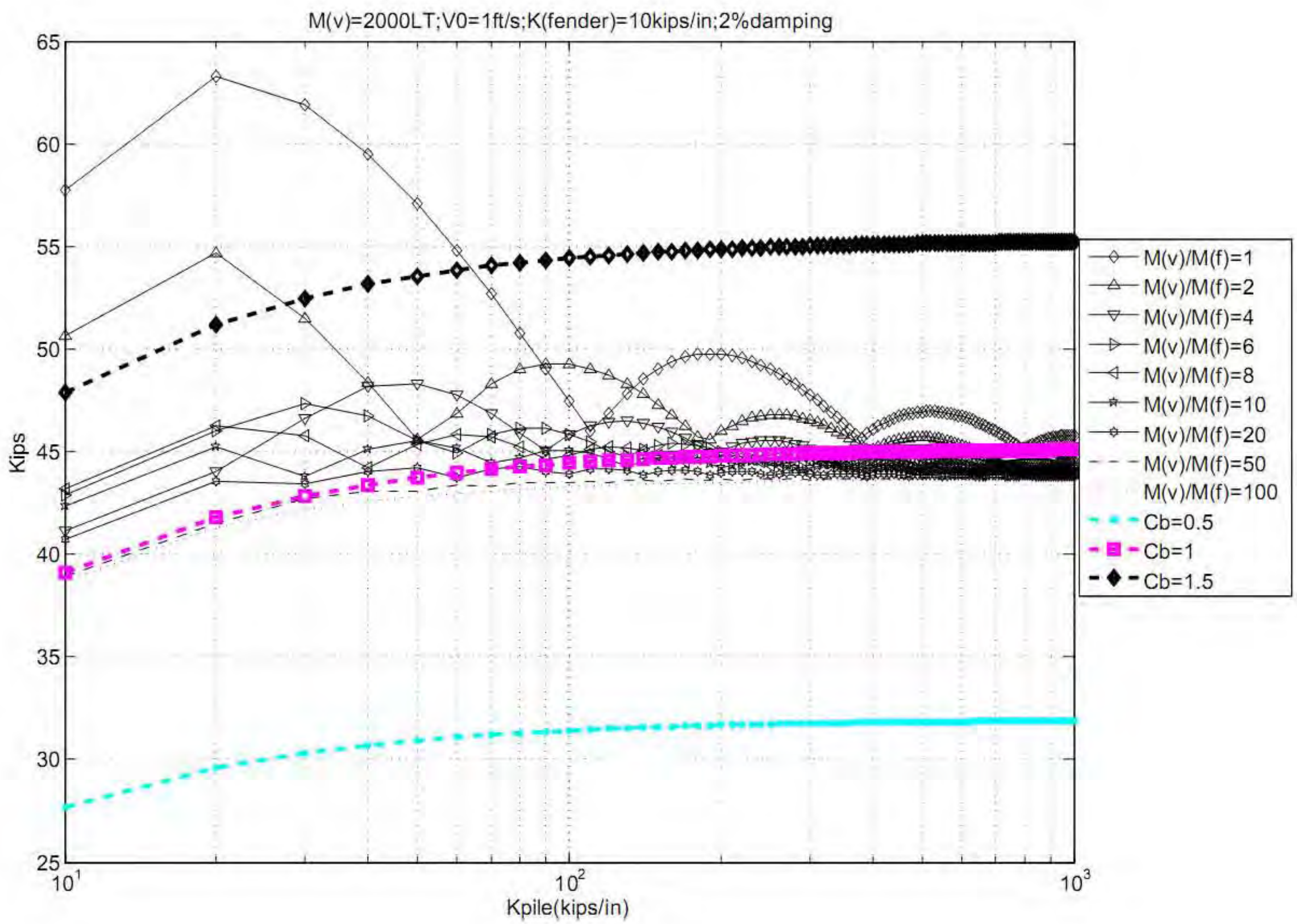
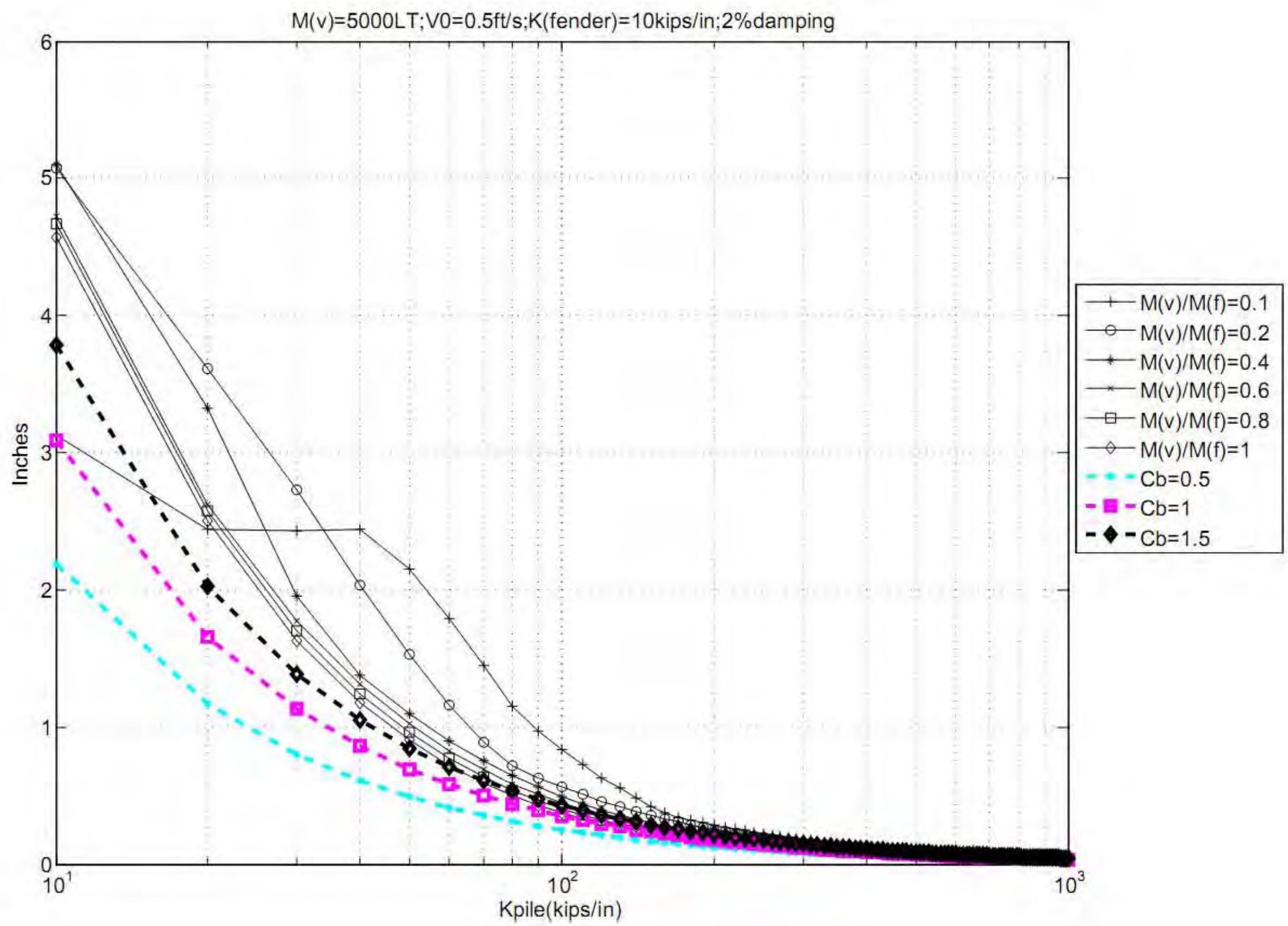
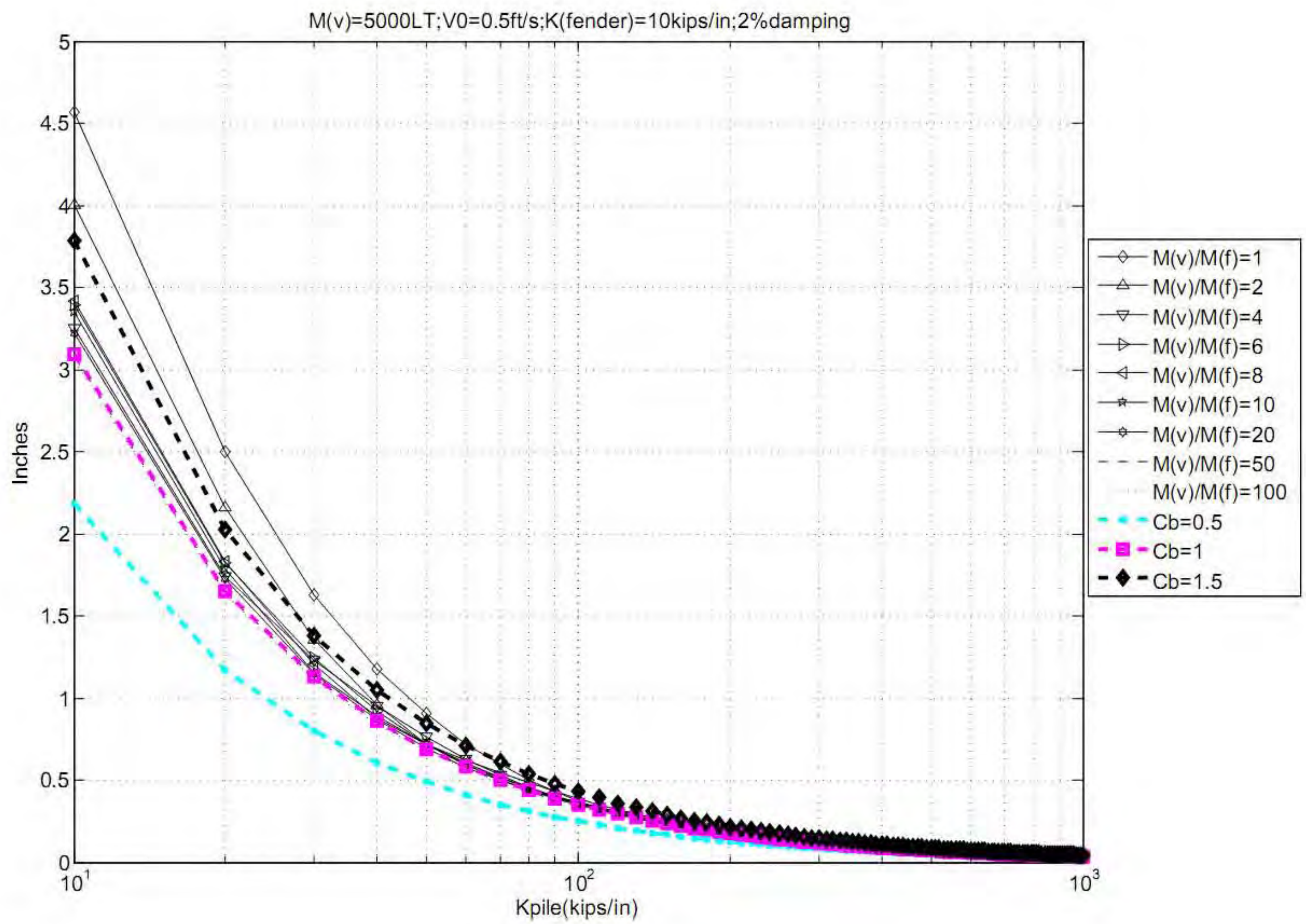

M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
65
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.16 Reaction Force of the Piling System 1D-4b



M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
0
1
2
3
4
5
6
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.17 Displacement of the Piling System 1D-5a



M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.18 Displacement of the Piling System 1D-5b

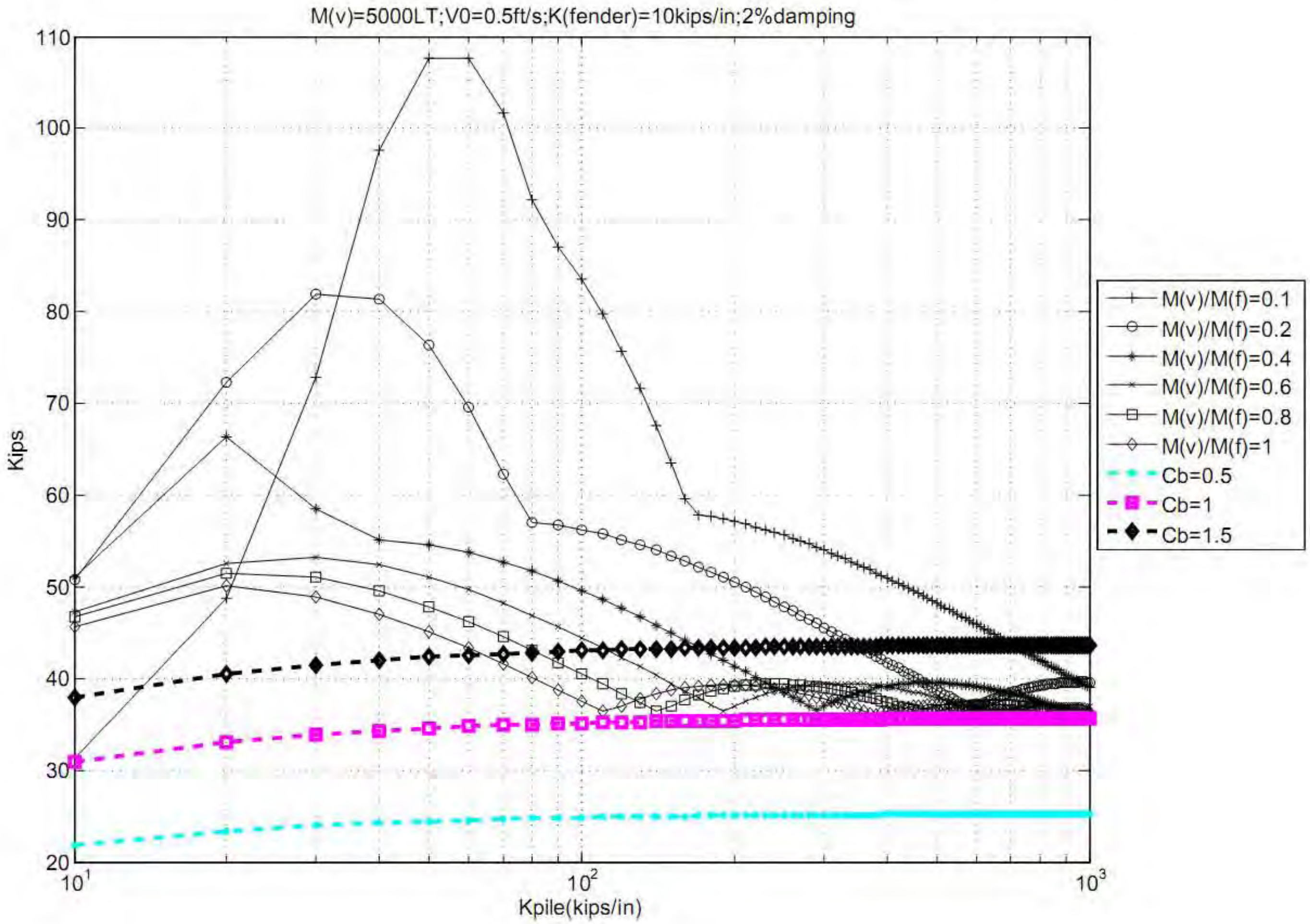
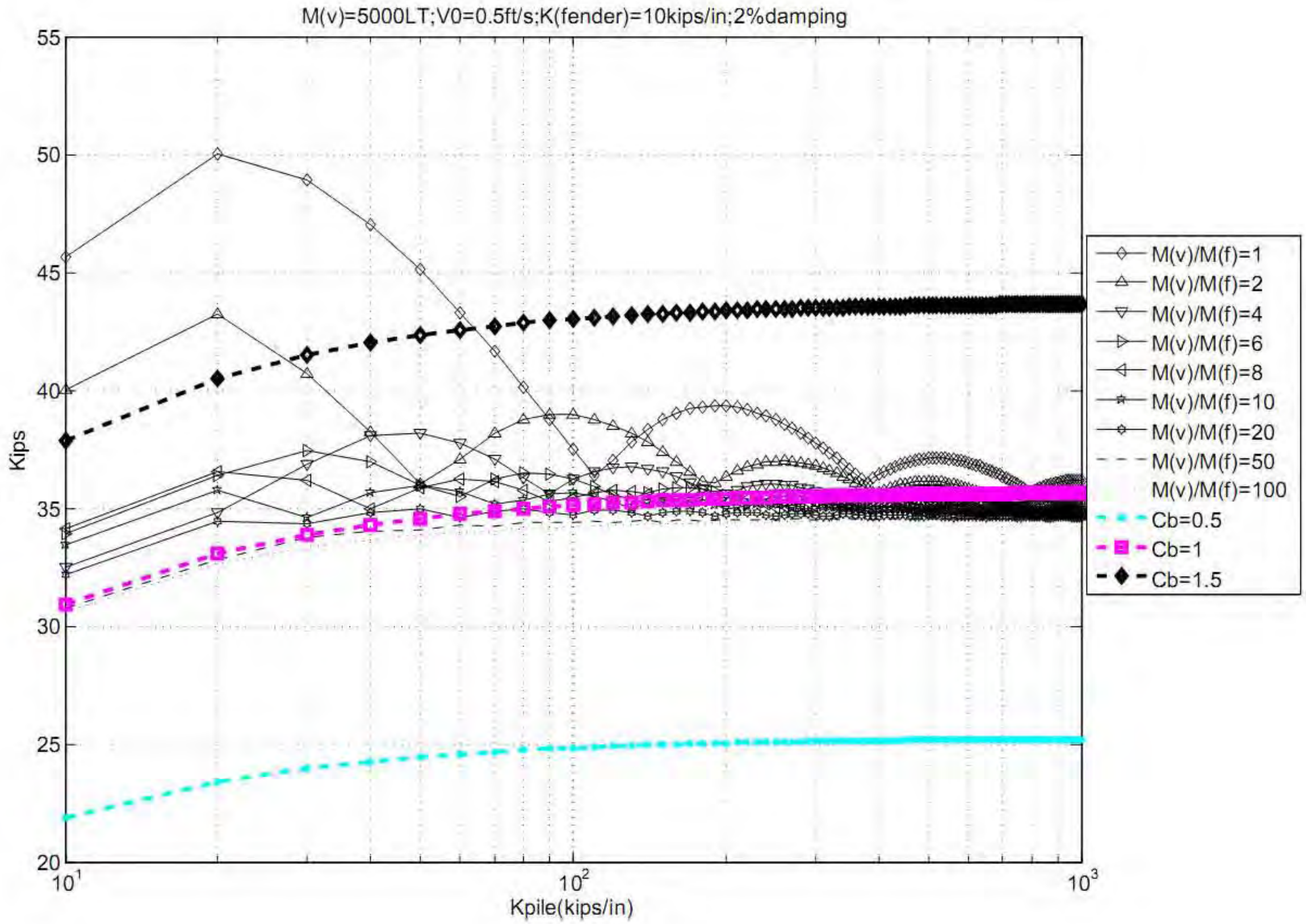
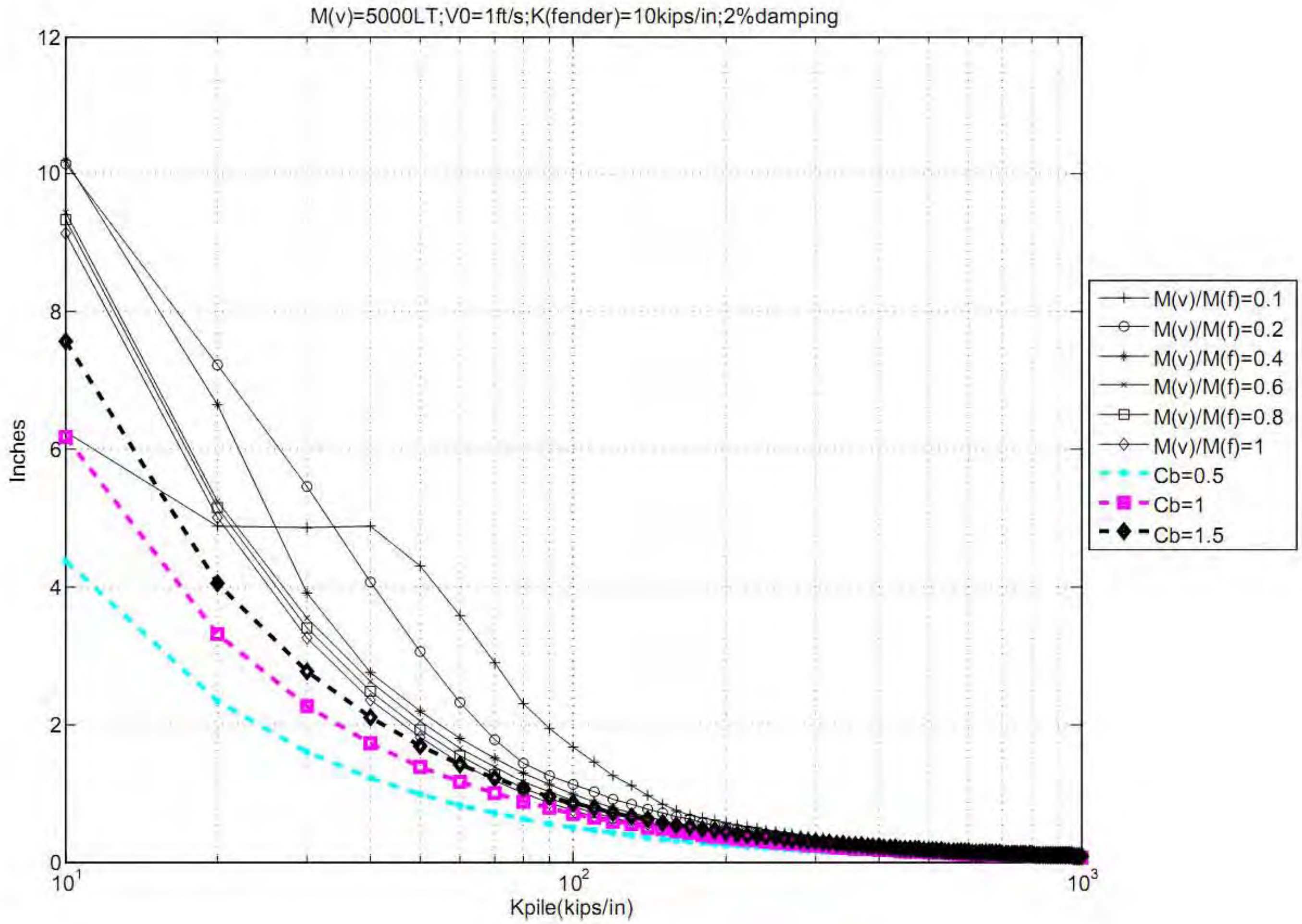

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
110
100
90
80
70
60
50
40
30
20
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.19 Reaction Force of the Piling System 1D-5a



M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
55
50
45
40
35
30
25
20
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.20 Reaction Force of the Piling System 1D-5b



M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.21 Displacement of the Piling System 1D-6a

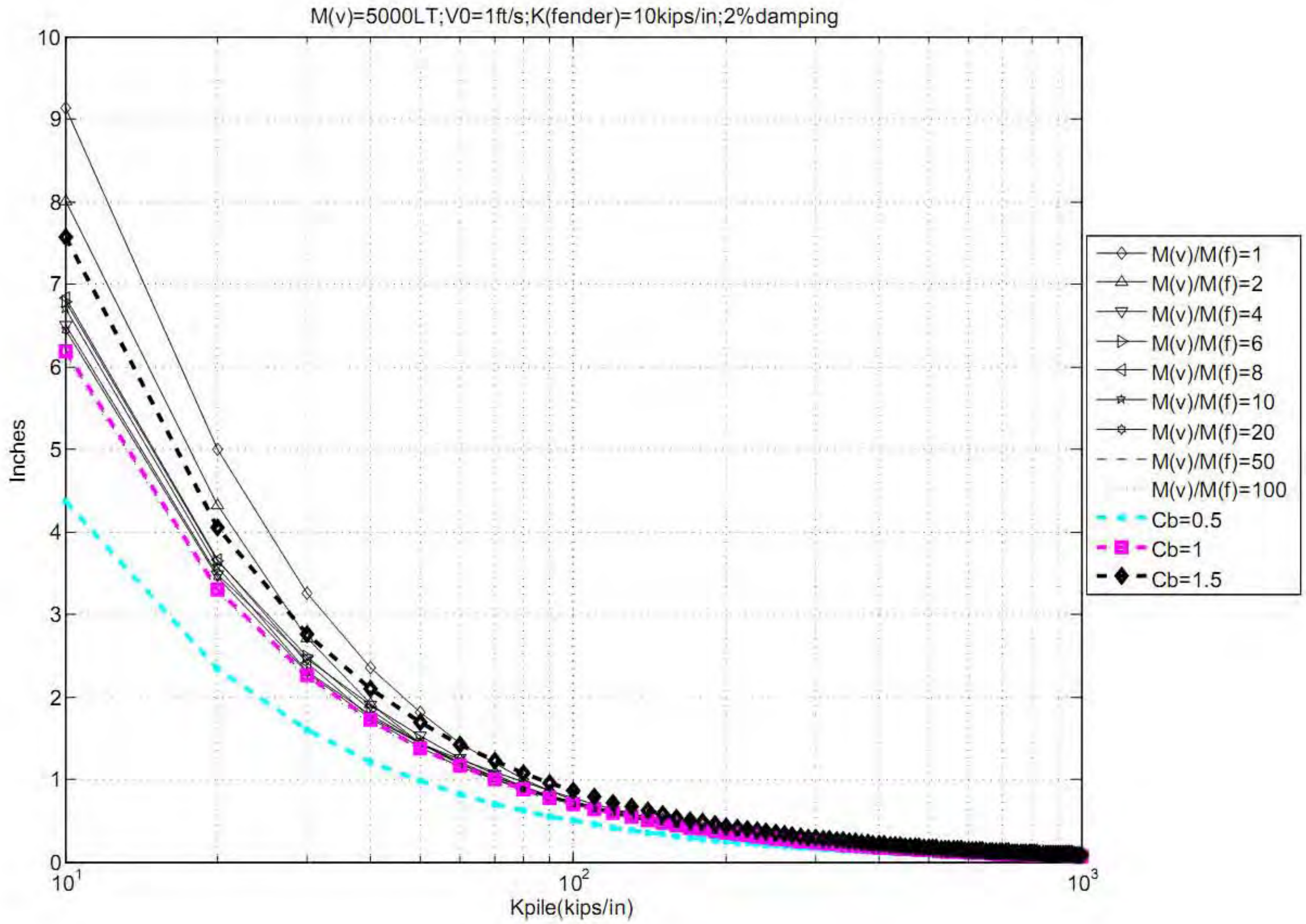

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.22 Displacement of the Piling System 1D-6b

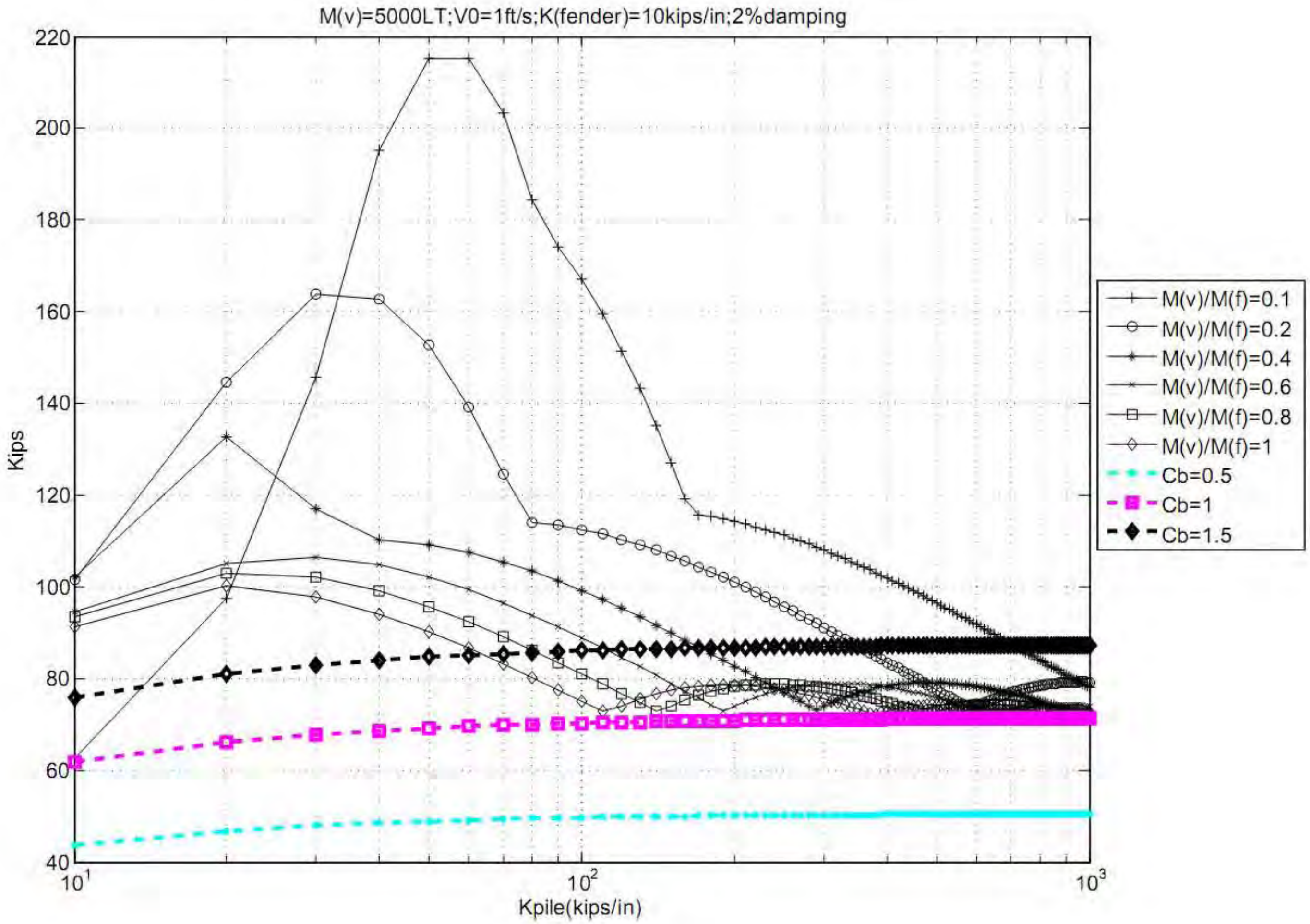

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.23 Reaction Force of the Piling System 1D-6a

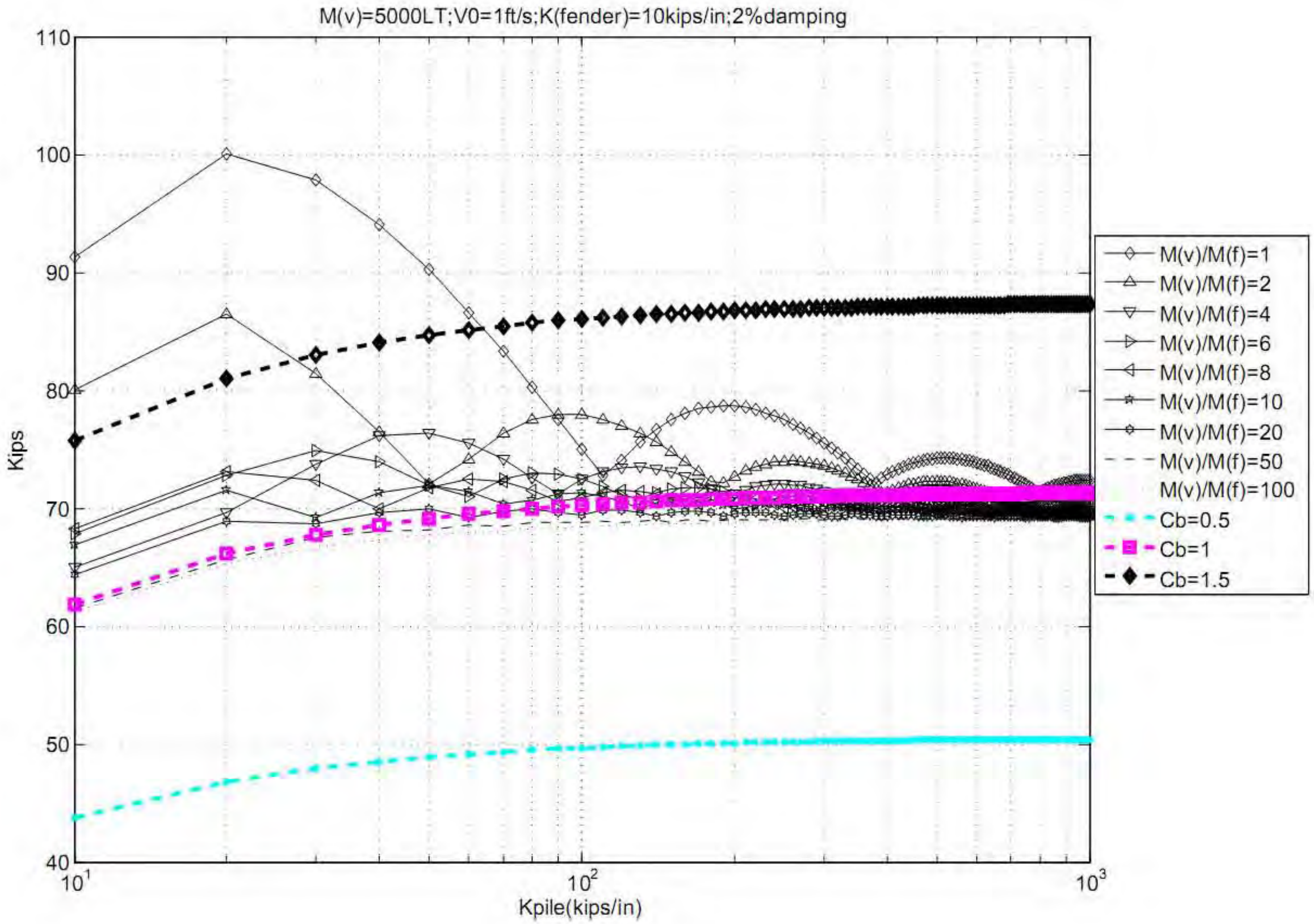
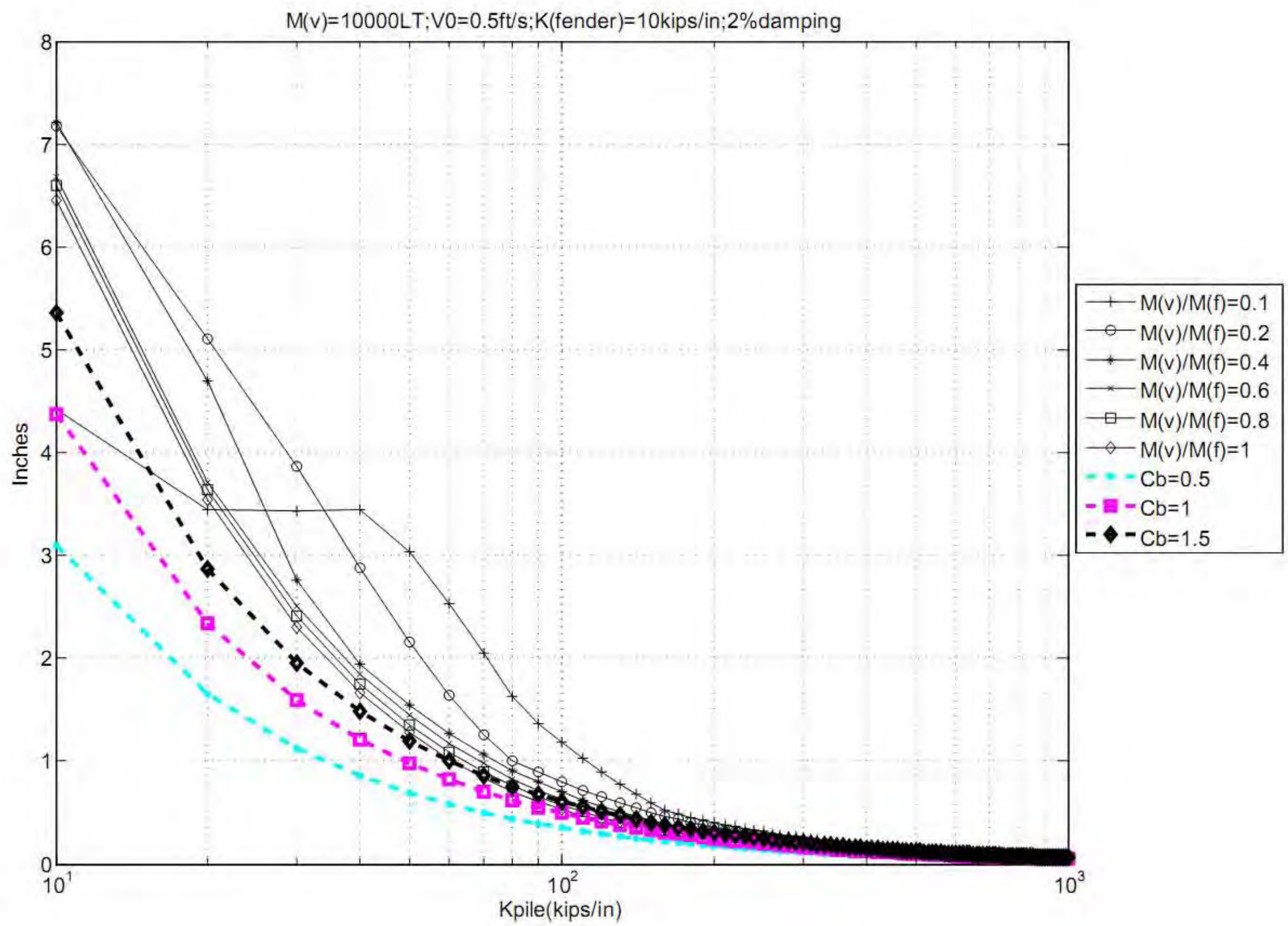
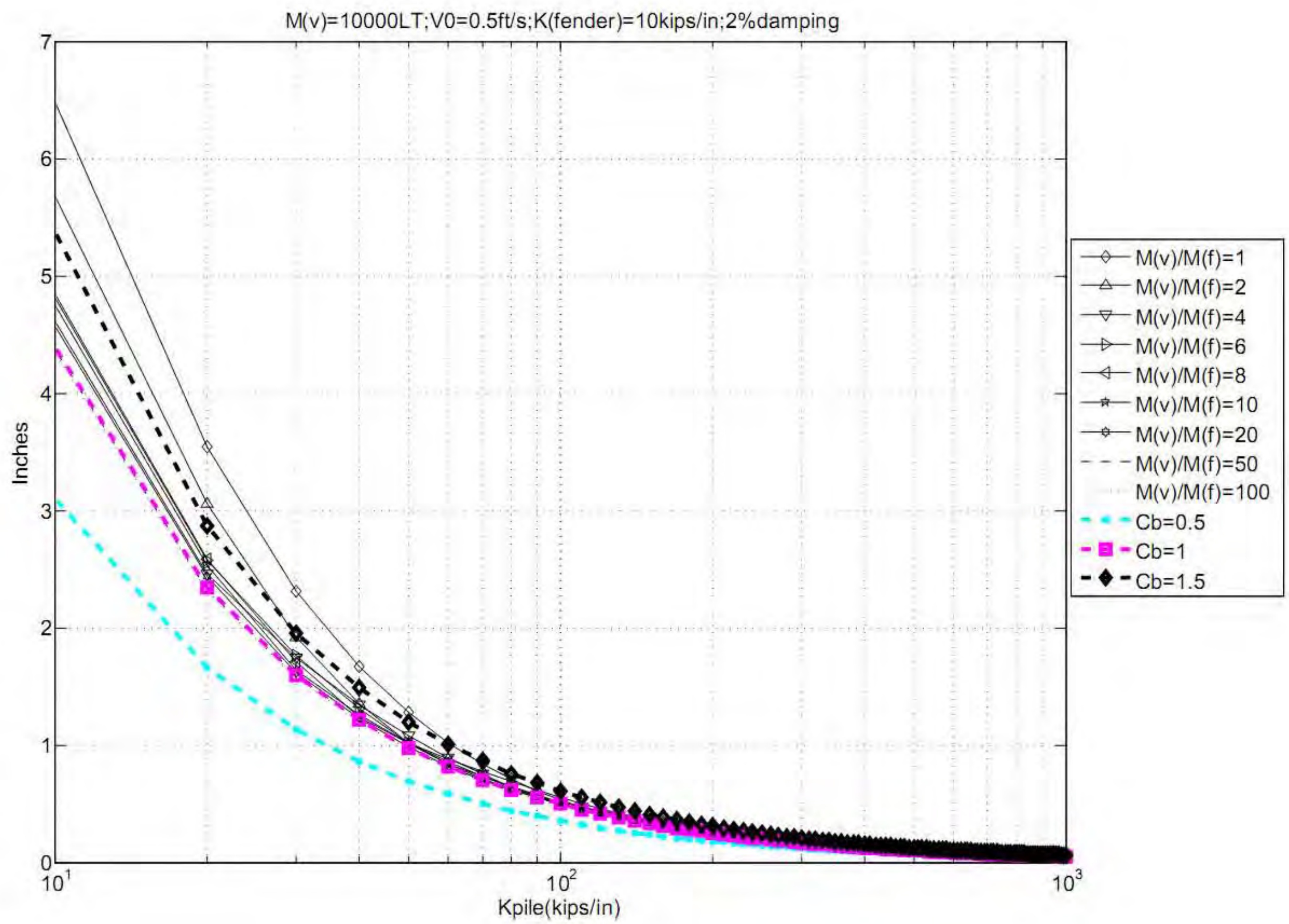

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
110
100
90
80
70
60
50
40
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.24 Reaction Force of the Piling System 1D-6b



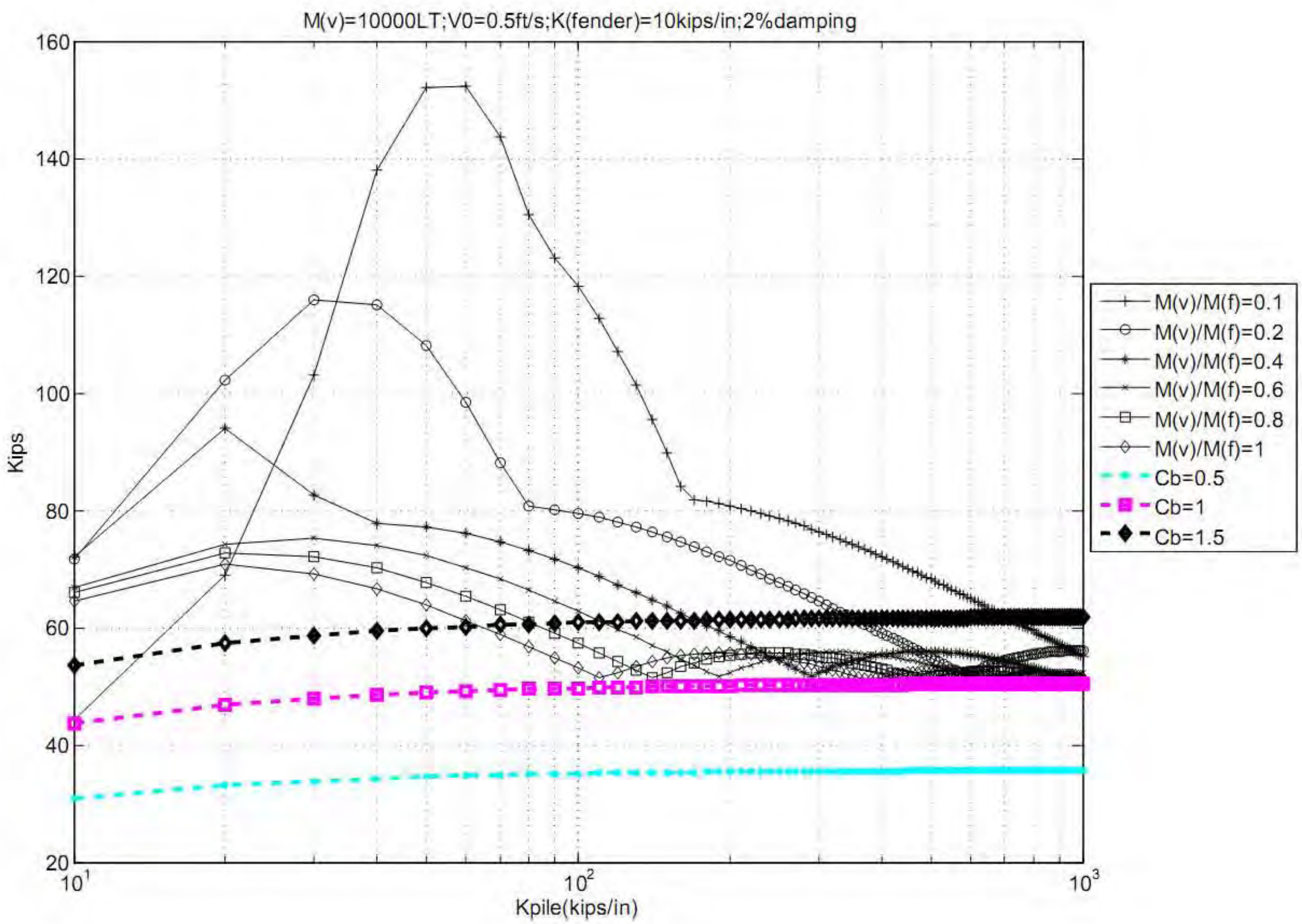
M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.25 Displacement of the Piling System 1D-7a



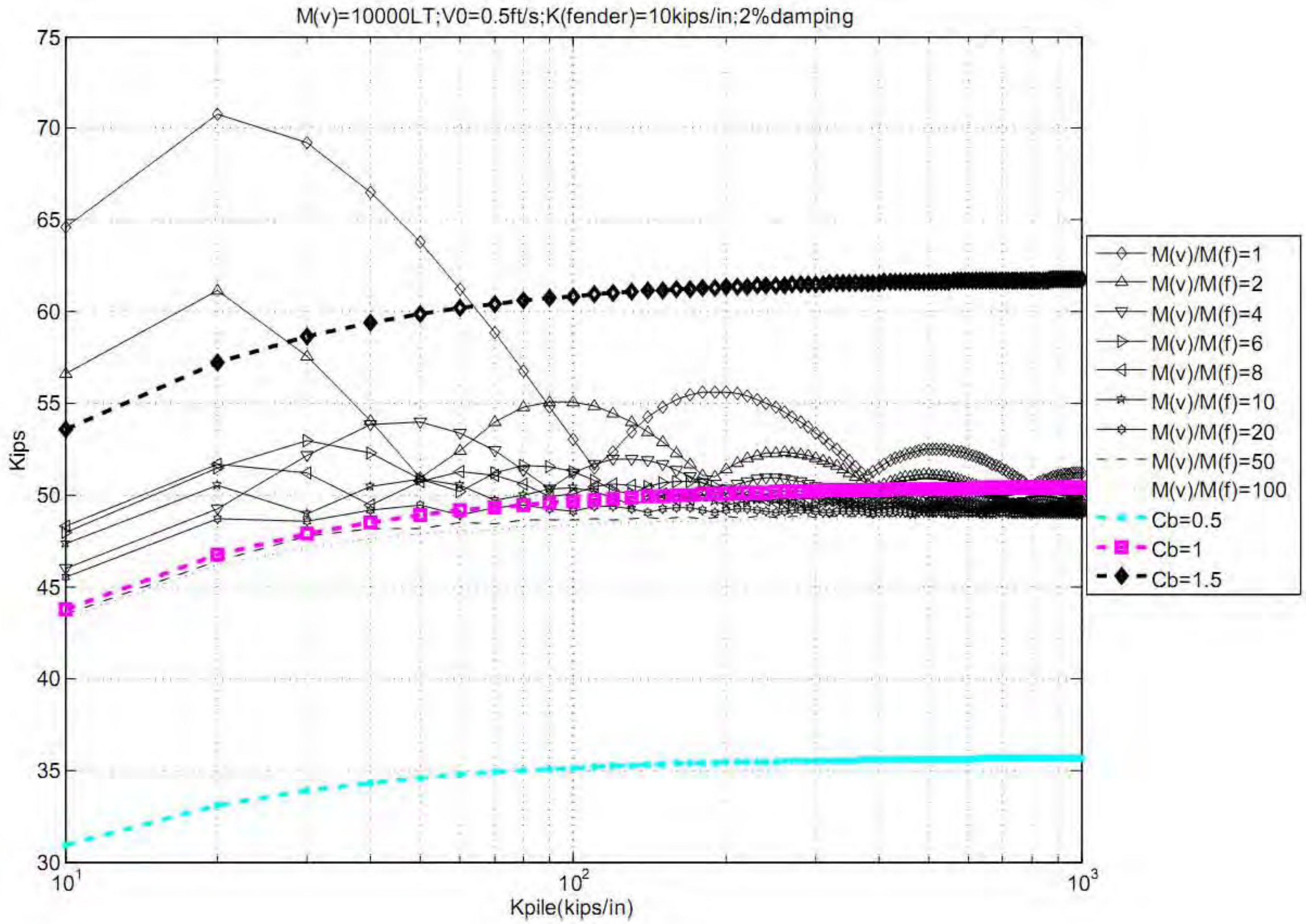
M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.26 Displacement of the Piling System 1D-7b



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
160
140
120
100
80
60
40
20
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.27 Reaction Force of the Piling System 1D-7a



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
75
70
65
60
55
50
45
40
35
30
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.28 Reaction Force of the Piling System 1D-7b

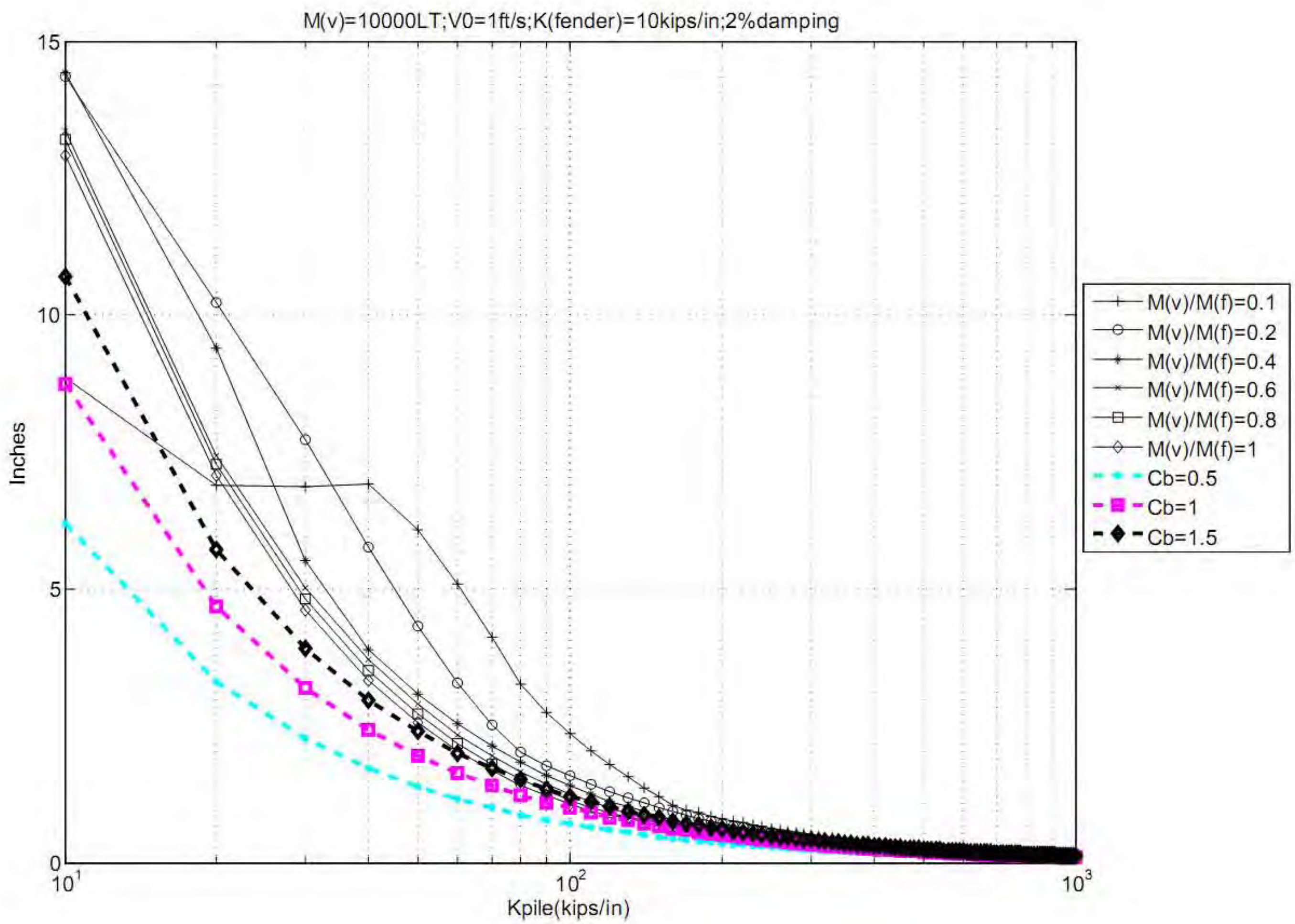
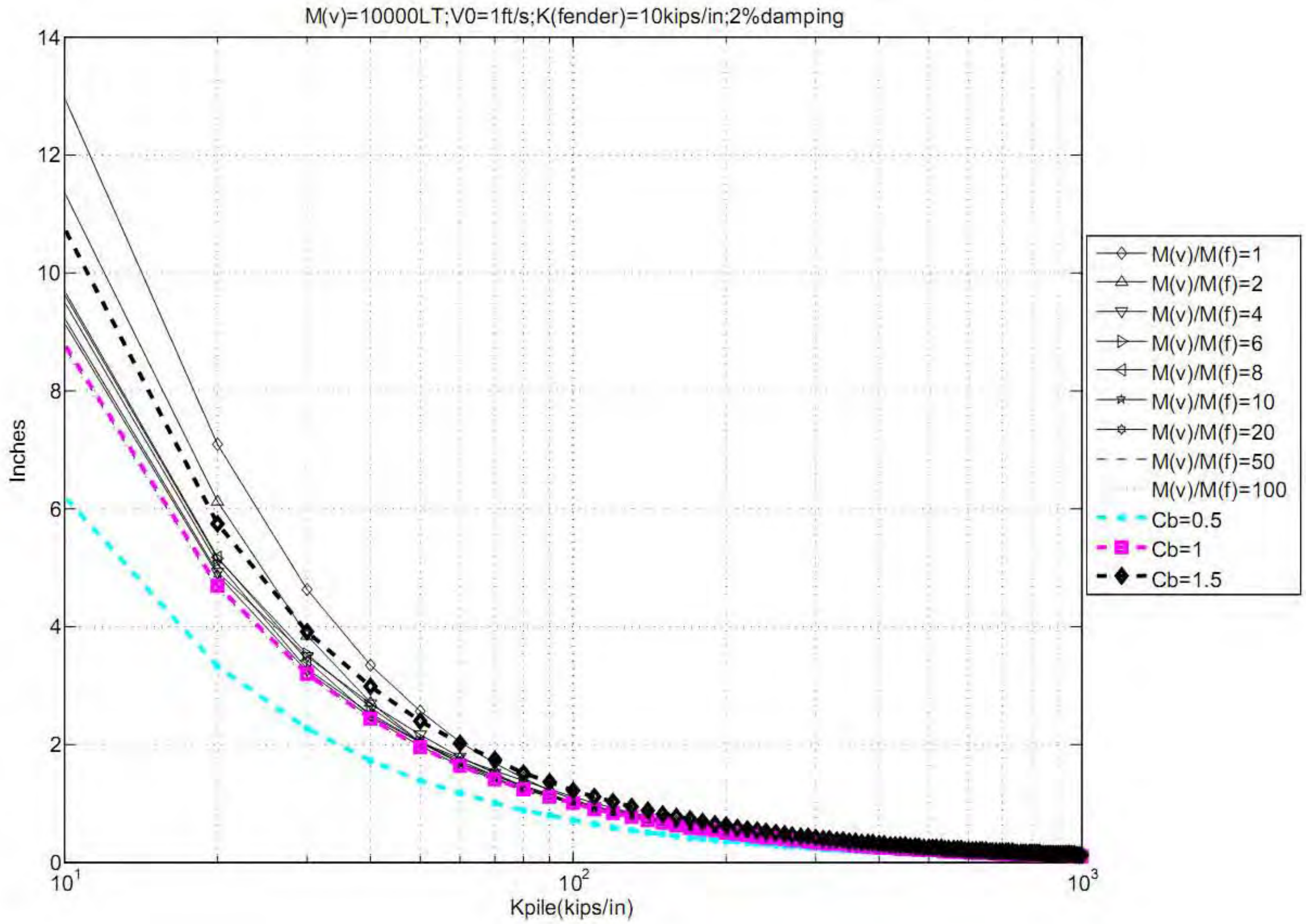
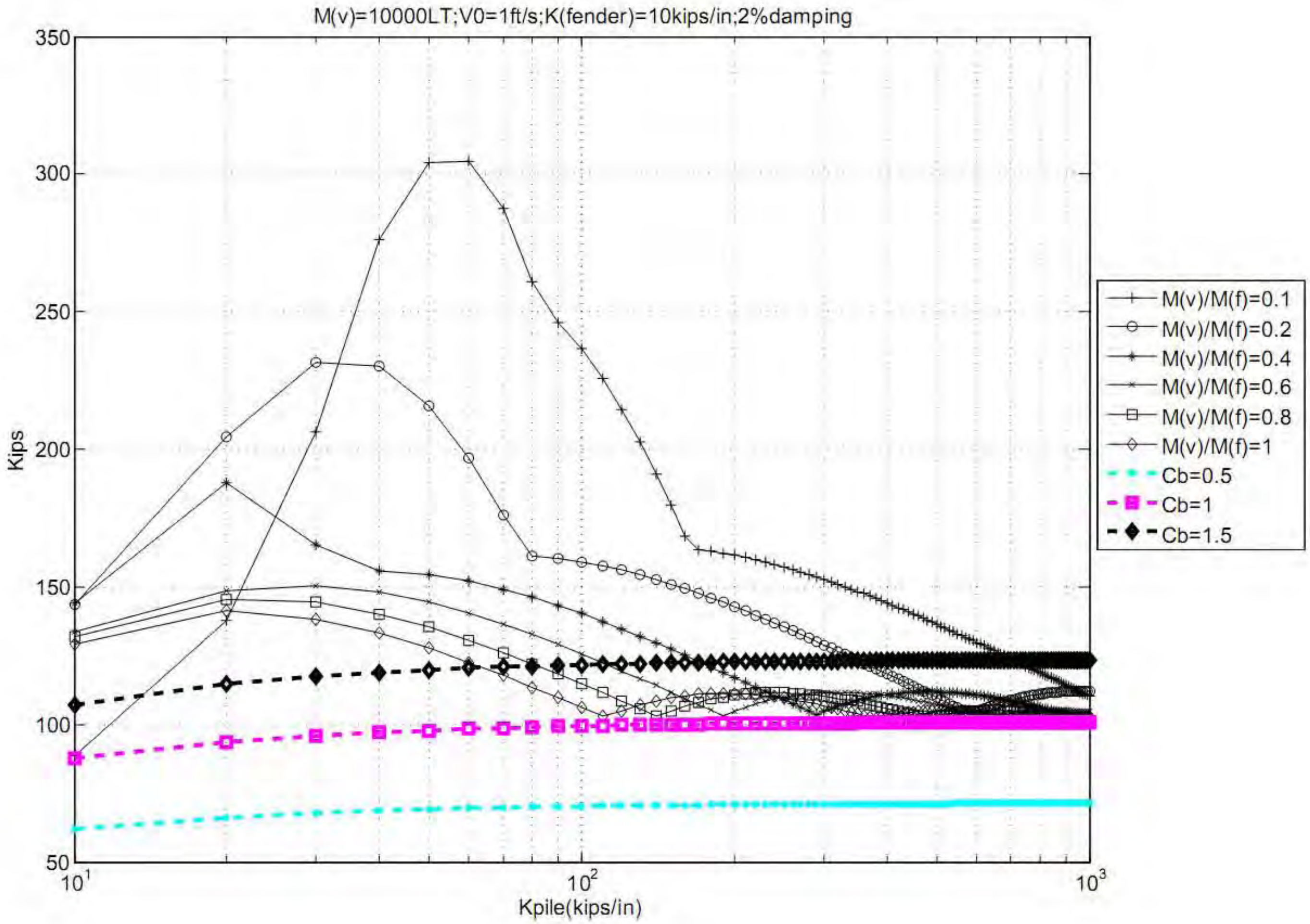

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.29 Displacement of the Piling System 1D-8a



M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.30 Displacement of the Piling System 1D-8b



M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
350
300
250
200
150
100
50
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.31 Reaction Force of the Piling System 1D-8a

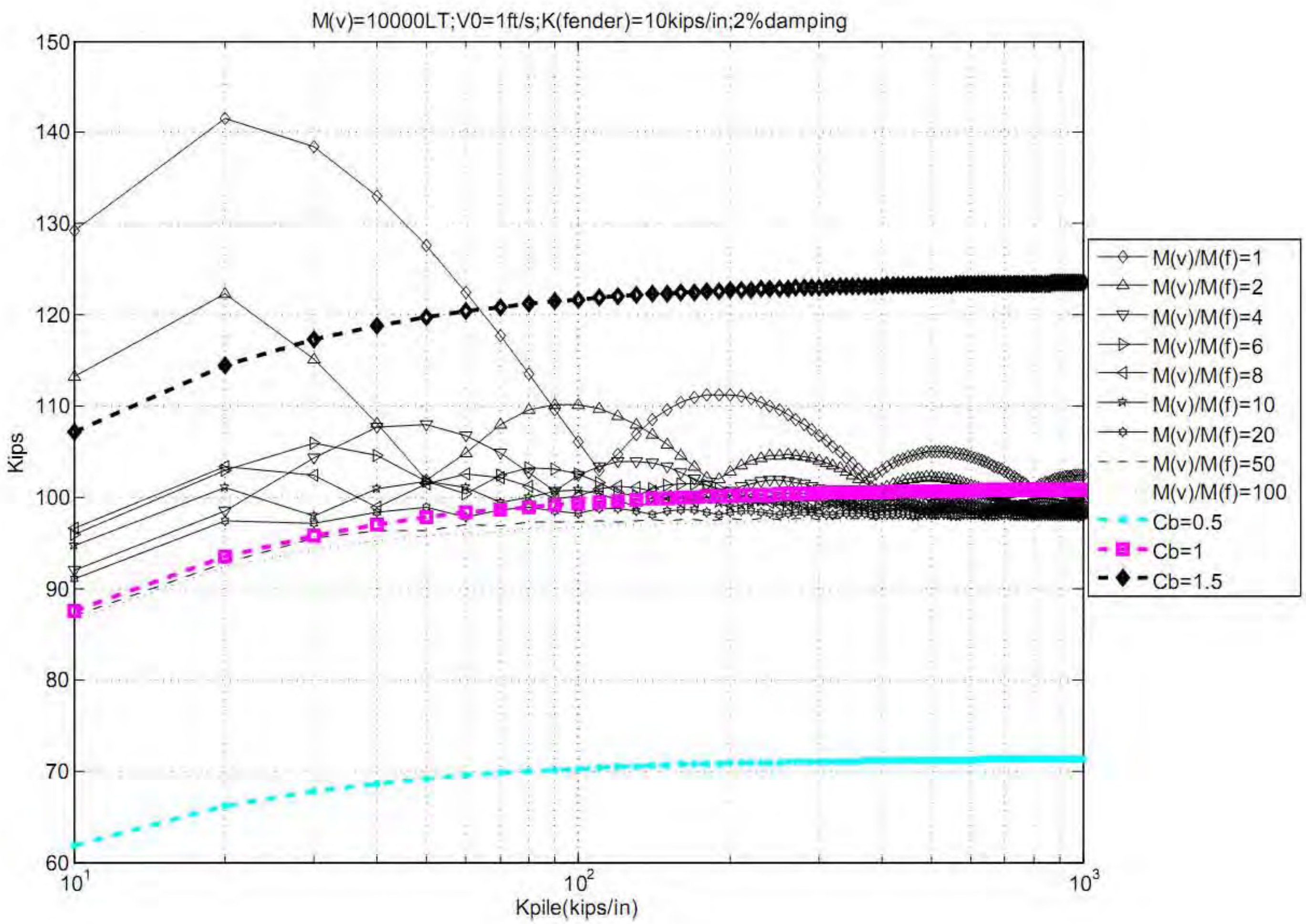

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;2%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.32 Reaction Force of the Piling System 1D-8b

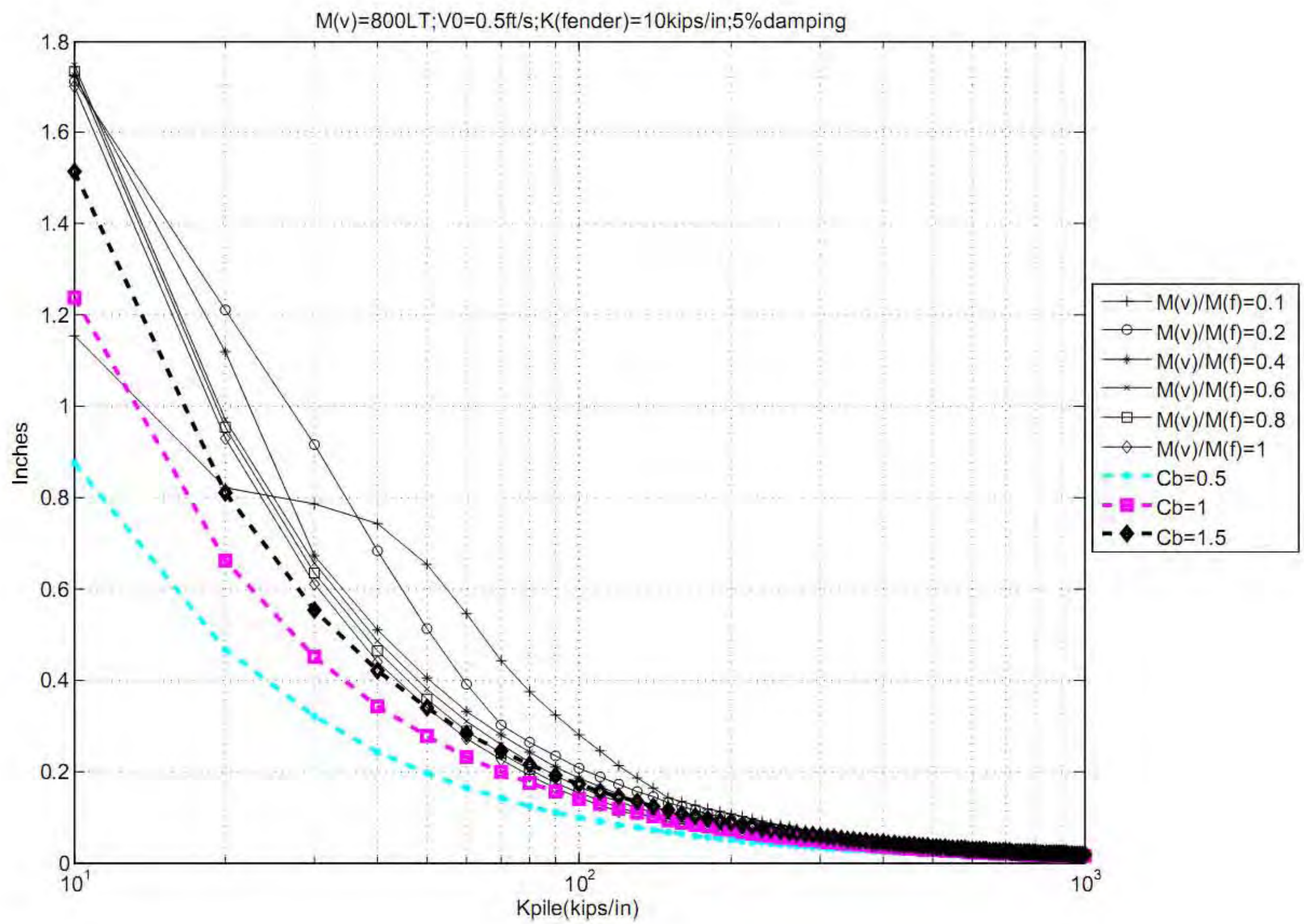

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.33 Displacement of the Piling System 1D-9a

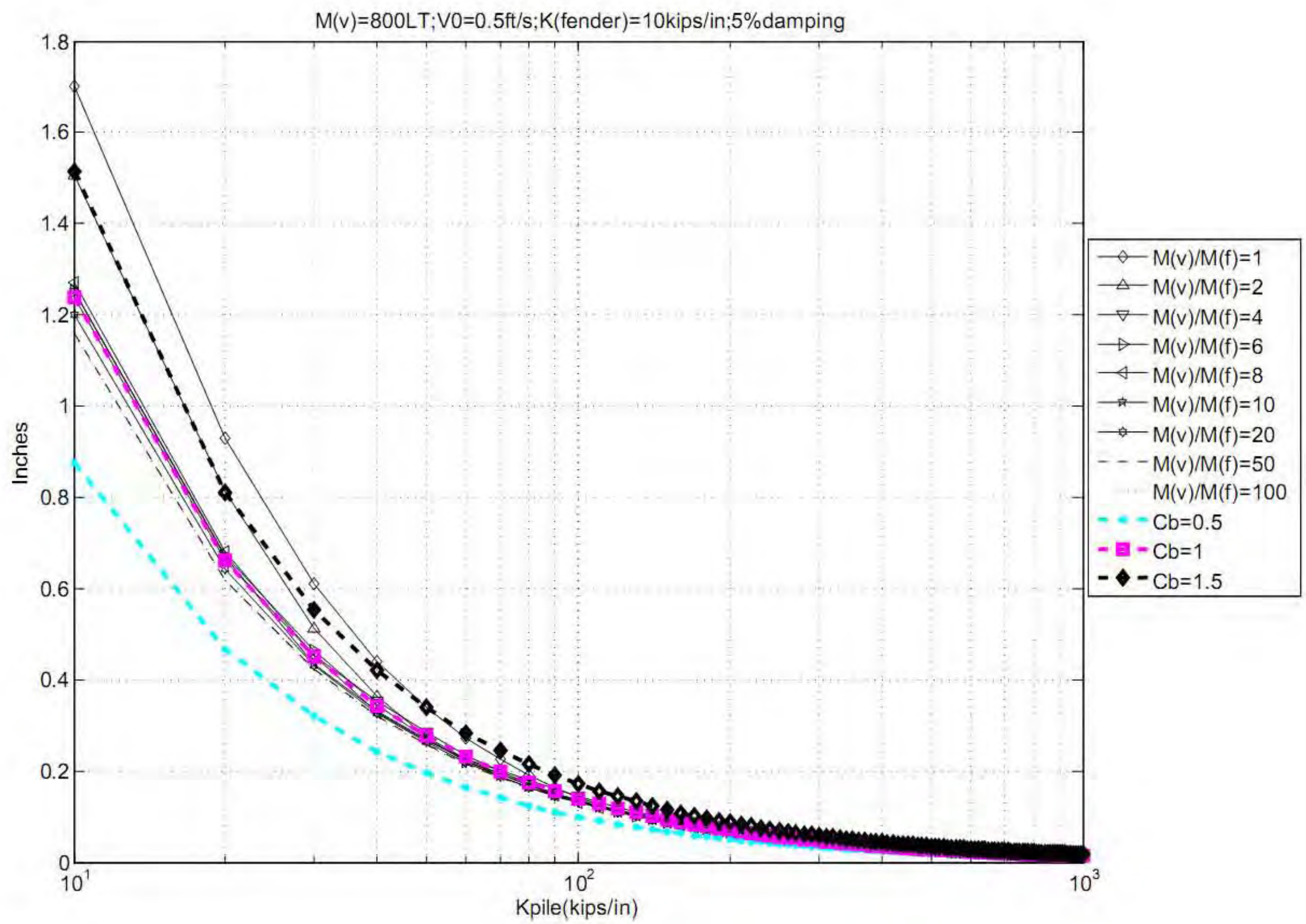
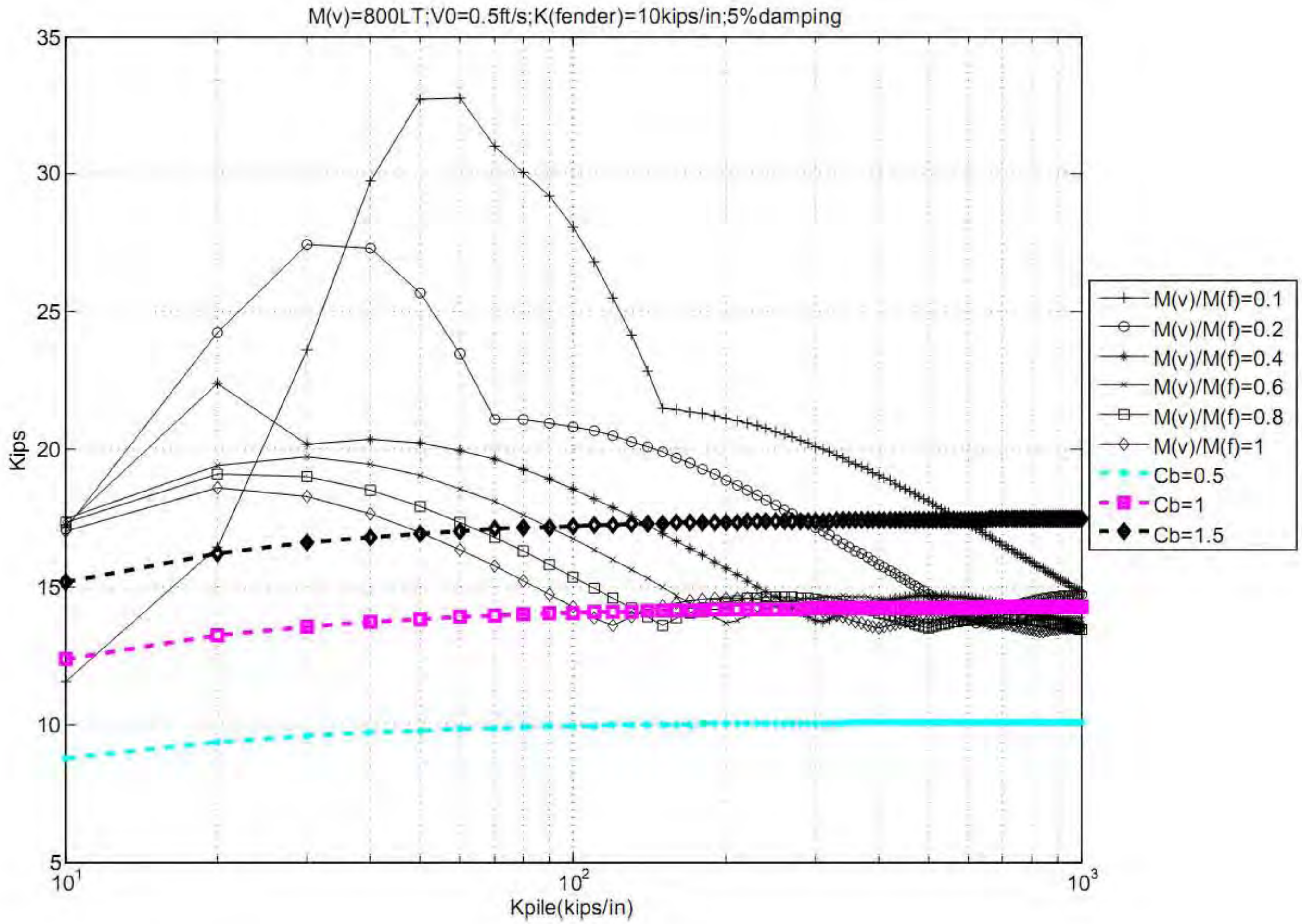

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.34 Displacement of the Piling System 1D-9b



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
35
30
25
20
15
10
5
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.35 Reaction Force of the Piling System 1D-9a

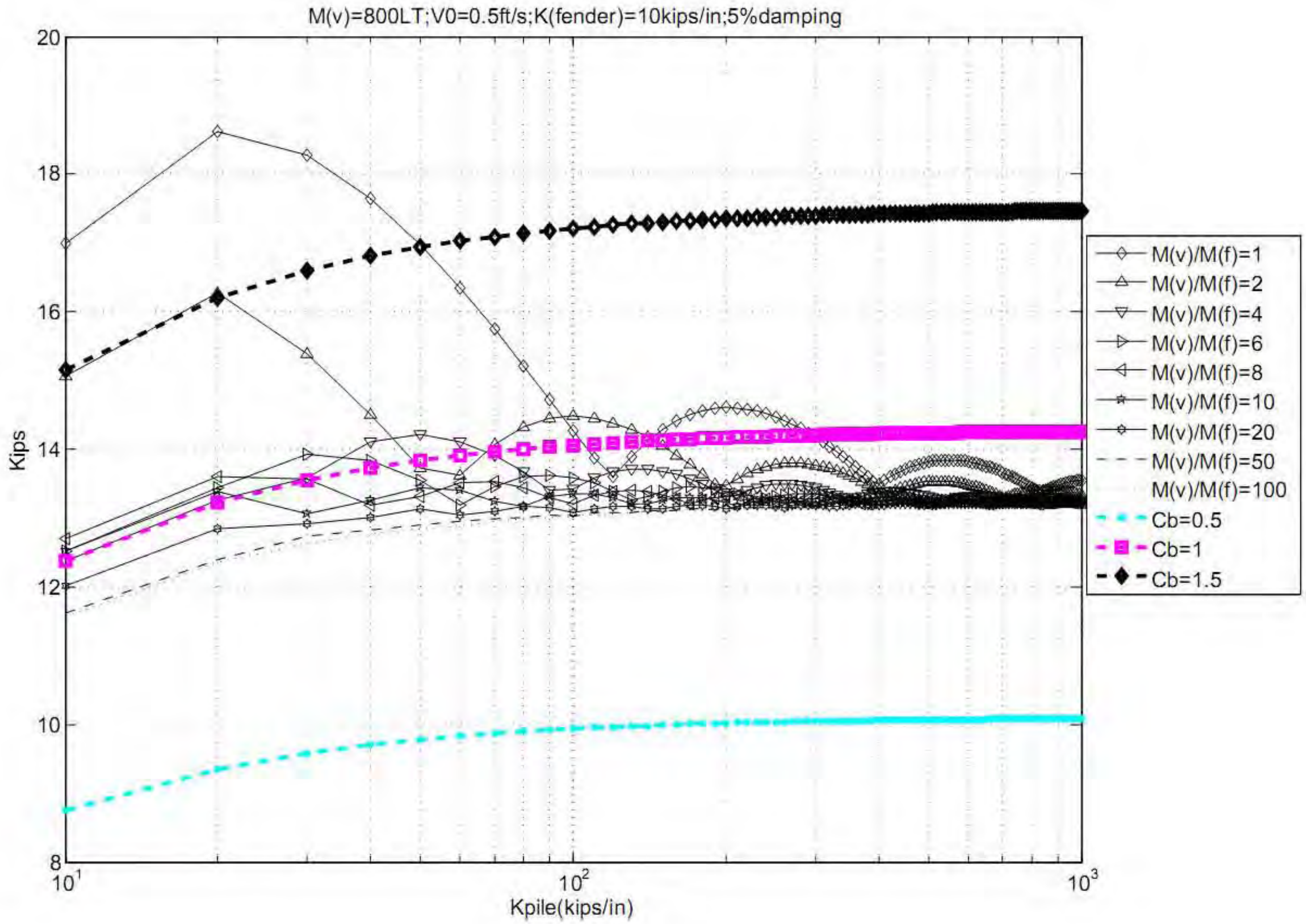

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
20
18
16
14
12
10
8
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.36 Reaction Force of the Piling System 1D-9b

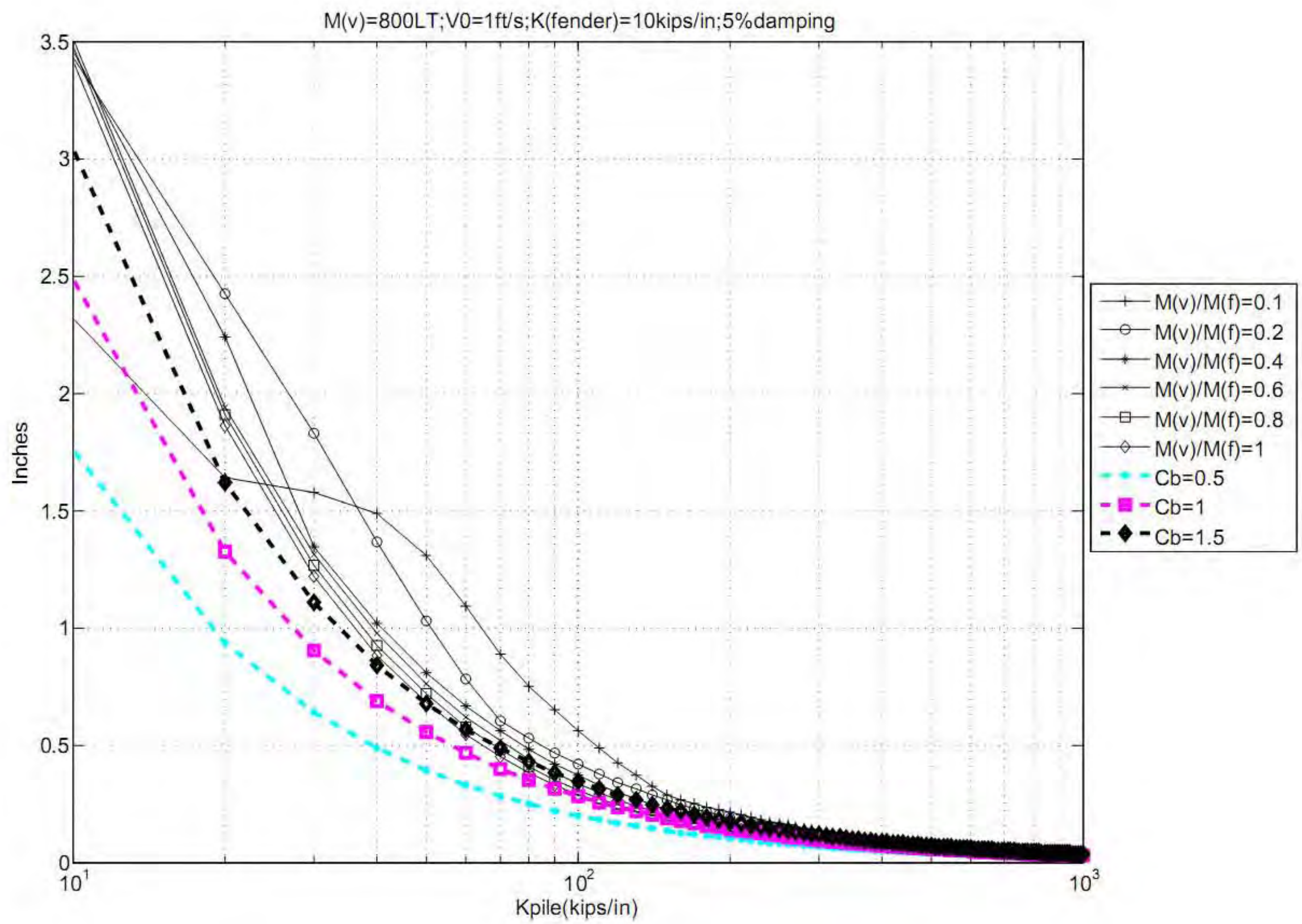

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.37 Displacement of the Piling System 1D-10a

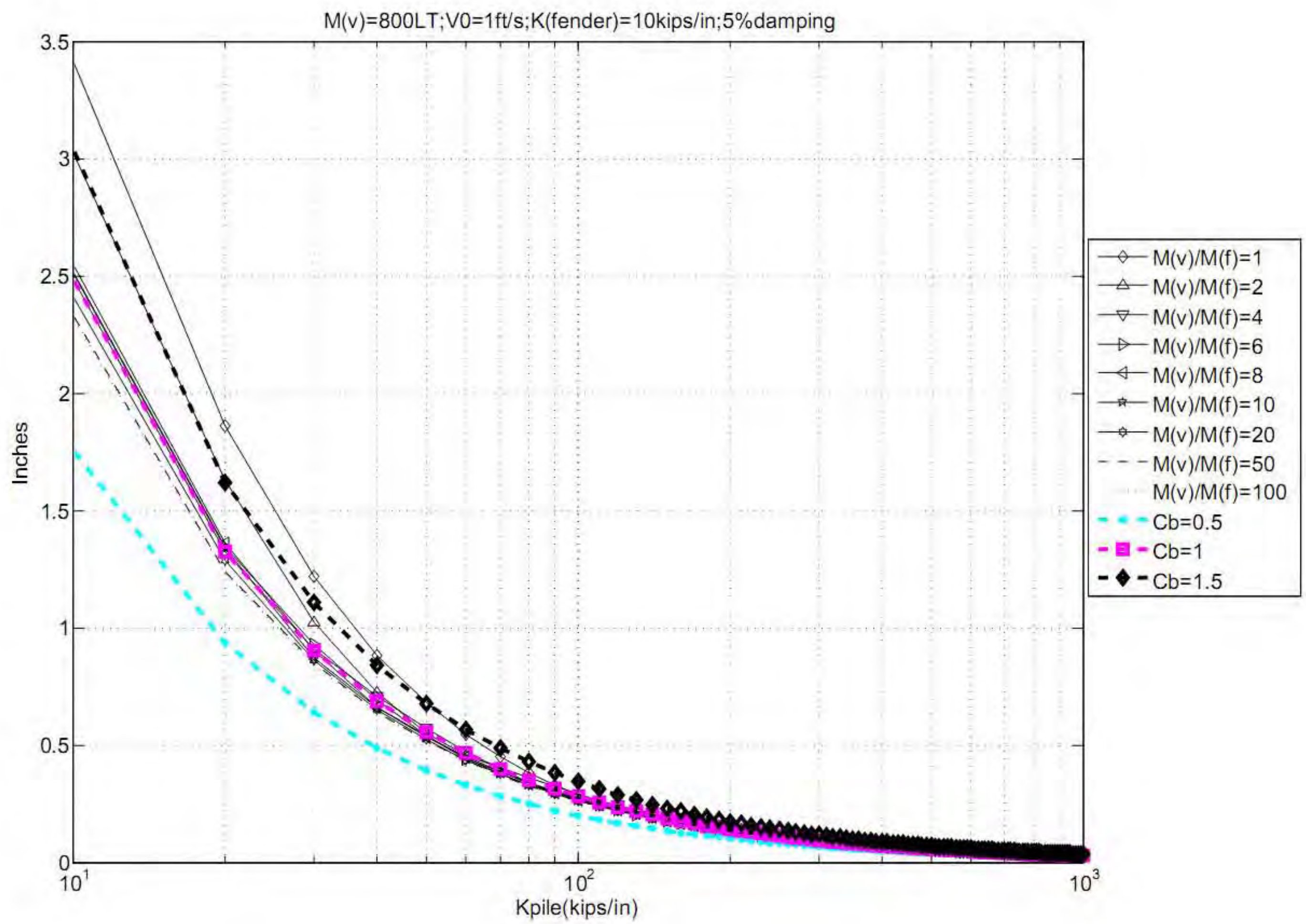

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;5%damping
3.5
3
2.5
2
1.5
1
0.5
0
Inches
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.38 Displacement of the Piling System 1D-10b

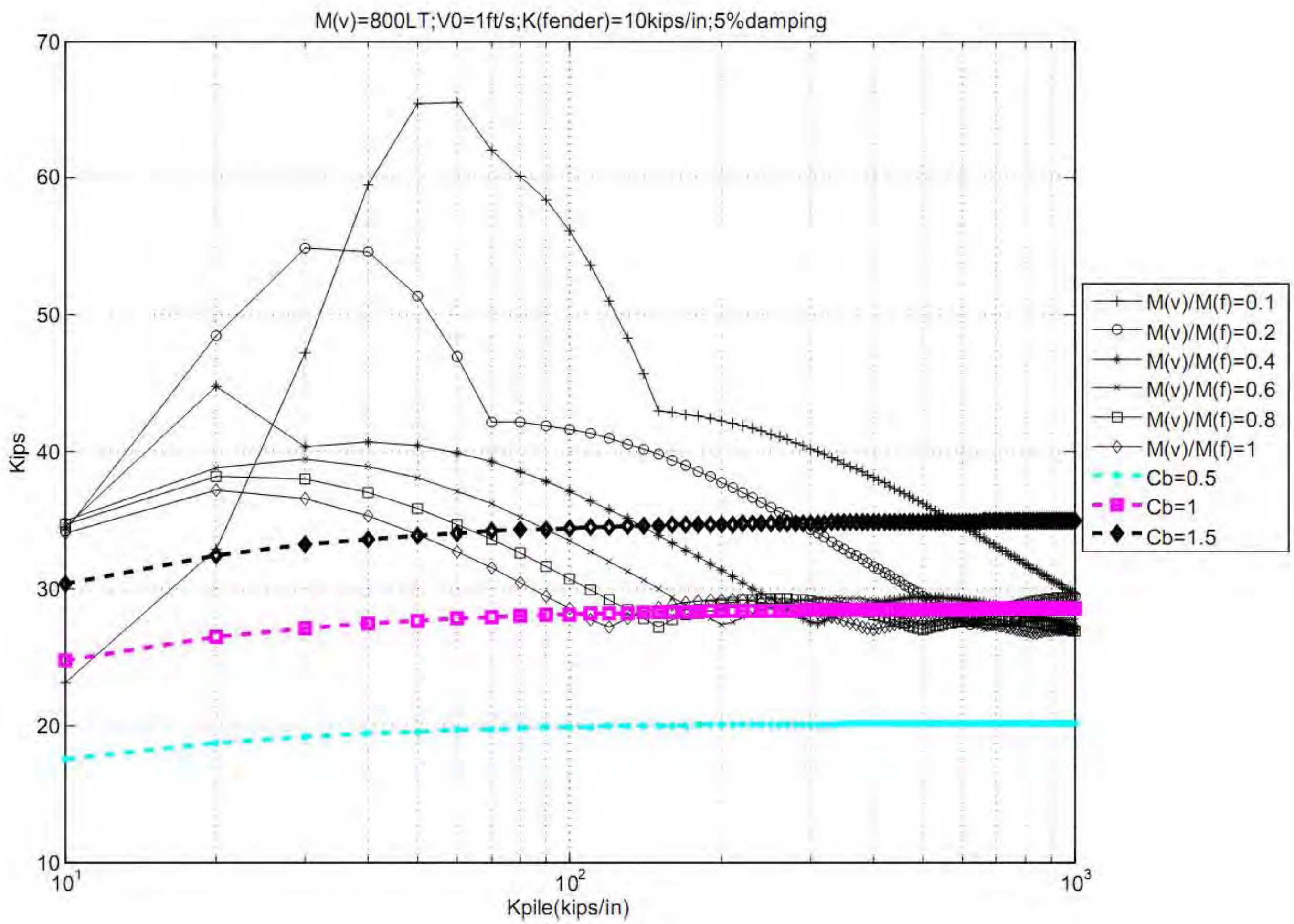

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
70
60
50
40
30
20
10
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.39 Reaction Force of the Piling System 1D-10a

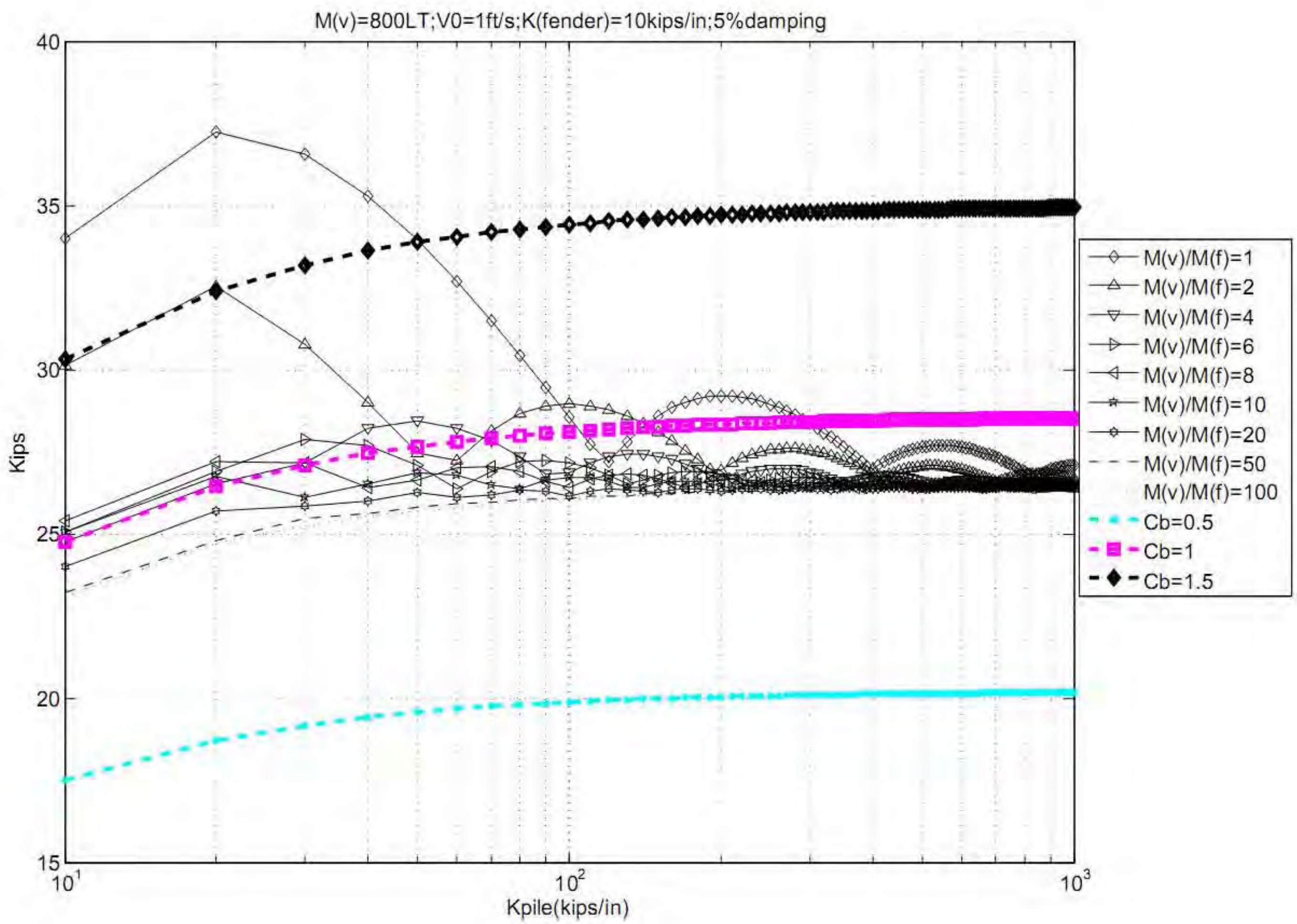
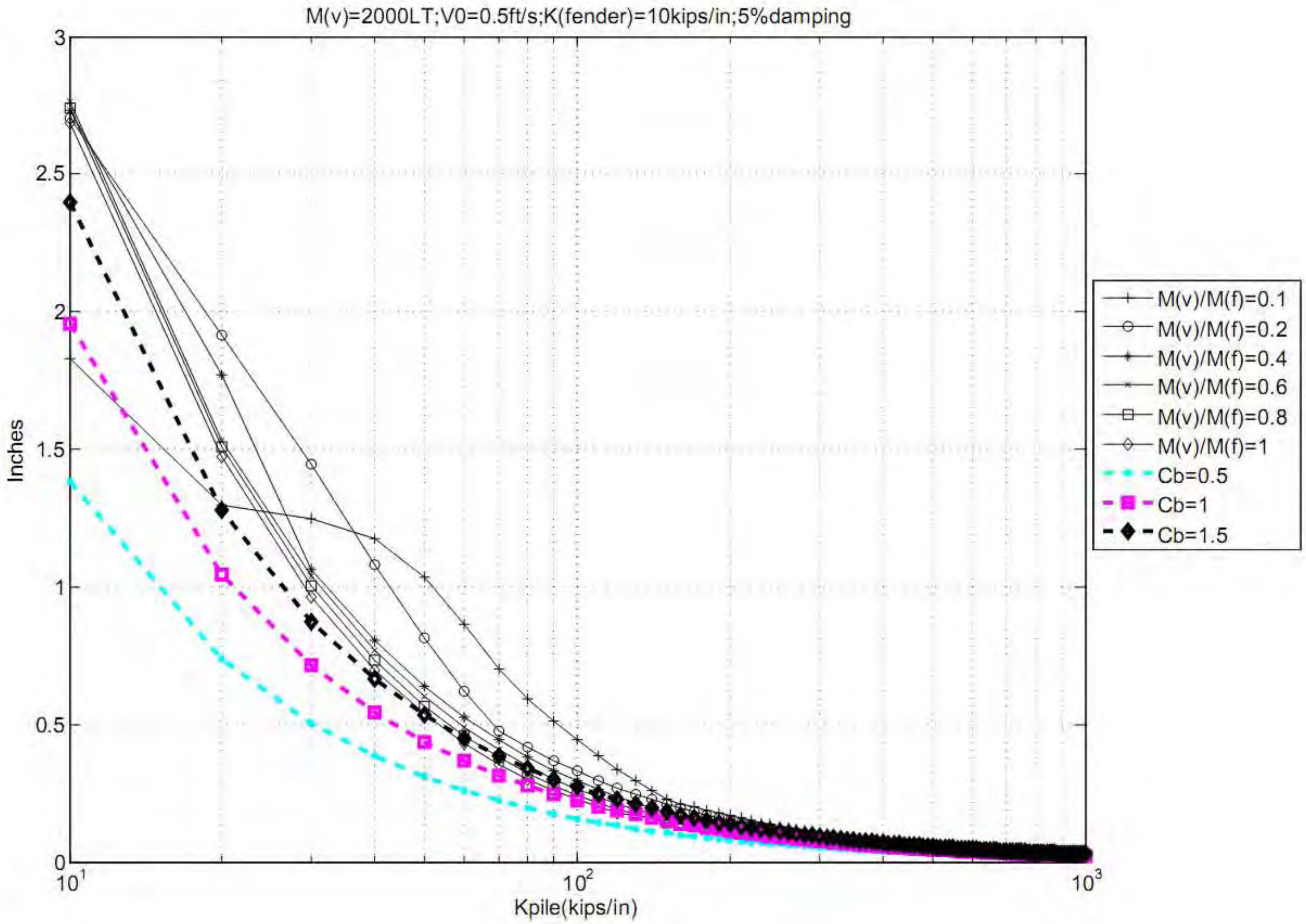
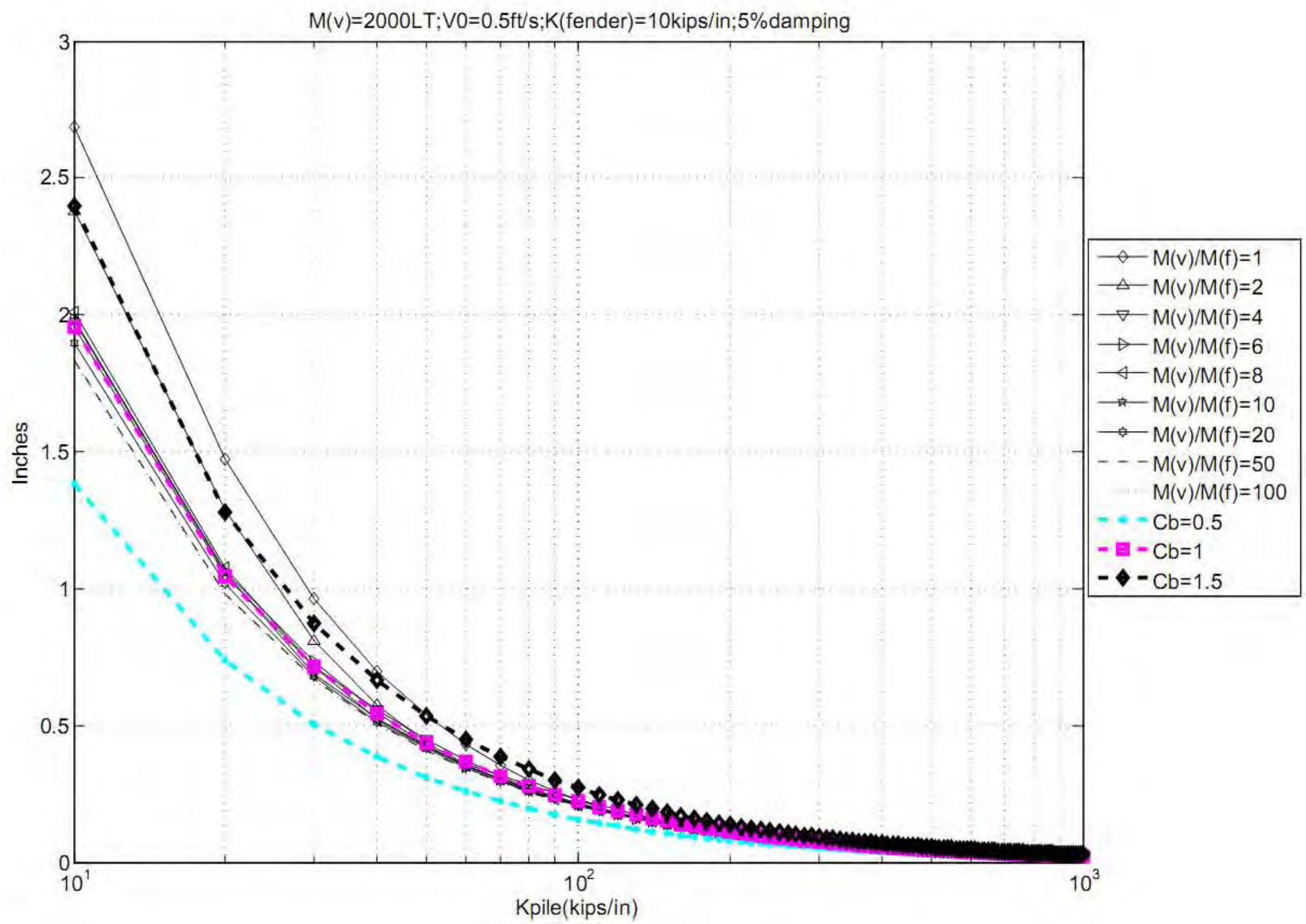

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;5%damping
40
35
30
25
20
15
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.40 Reaction Force of the Piling System 1D-10b



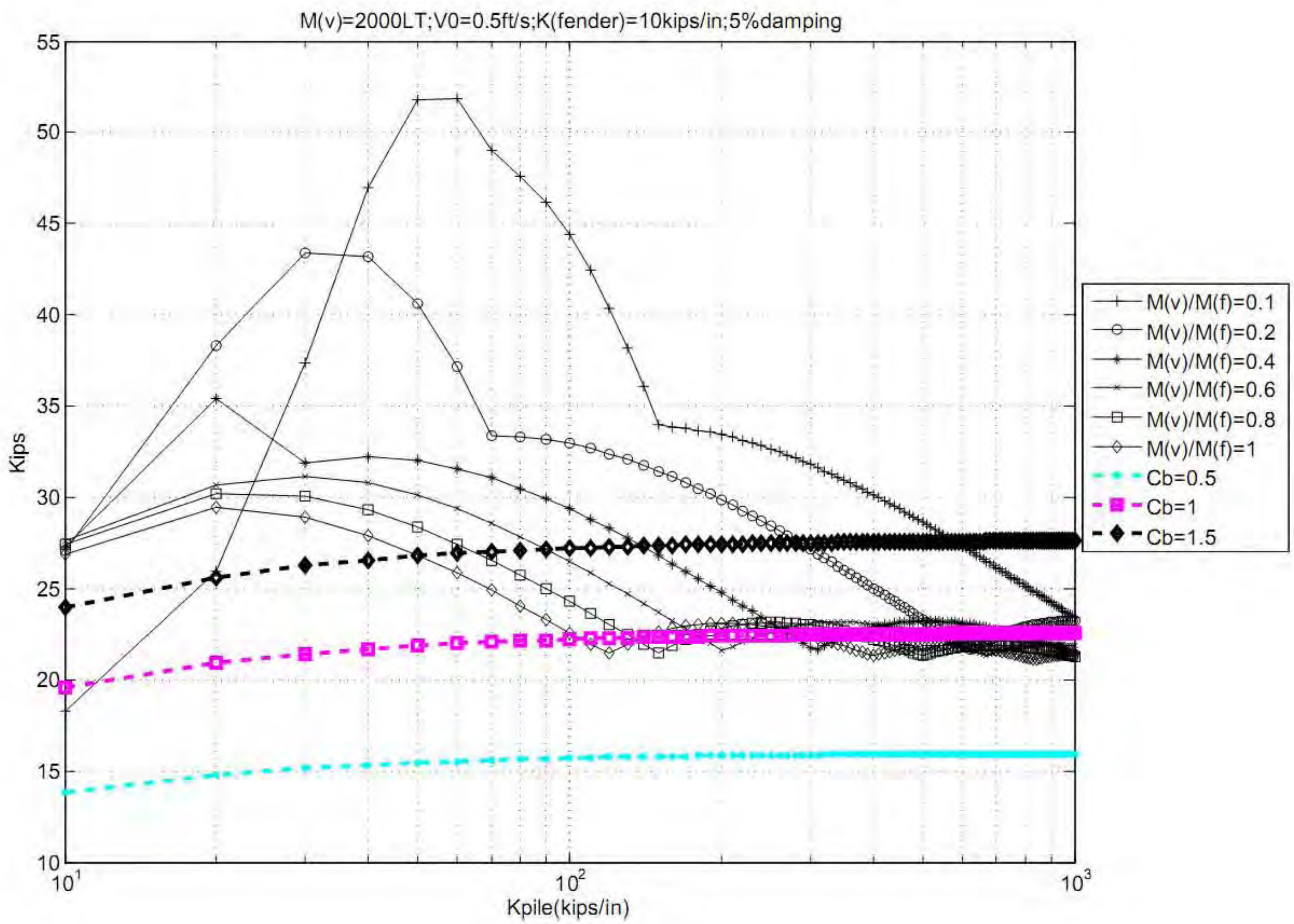
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.41 Displacement of the Piling System 1D-11a



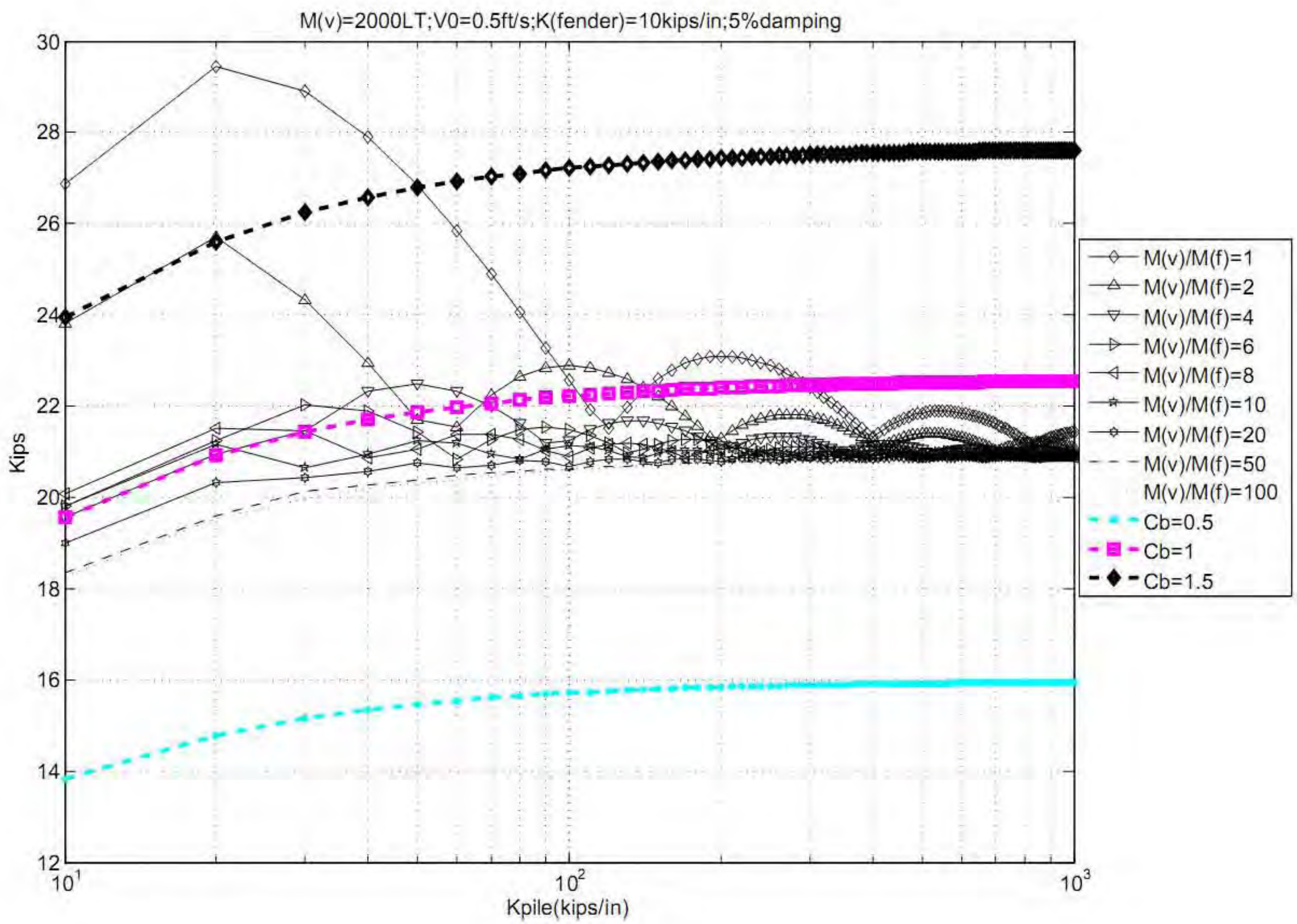
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.42 Displacement of the Piling System 1D-11b



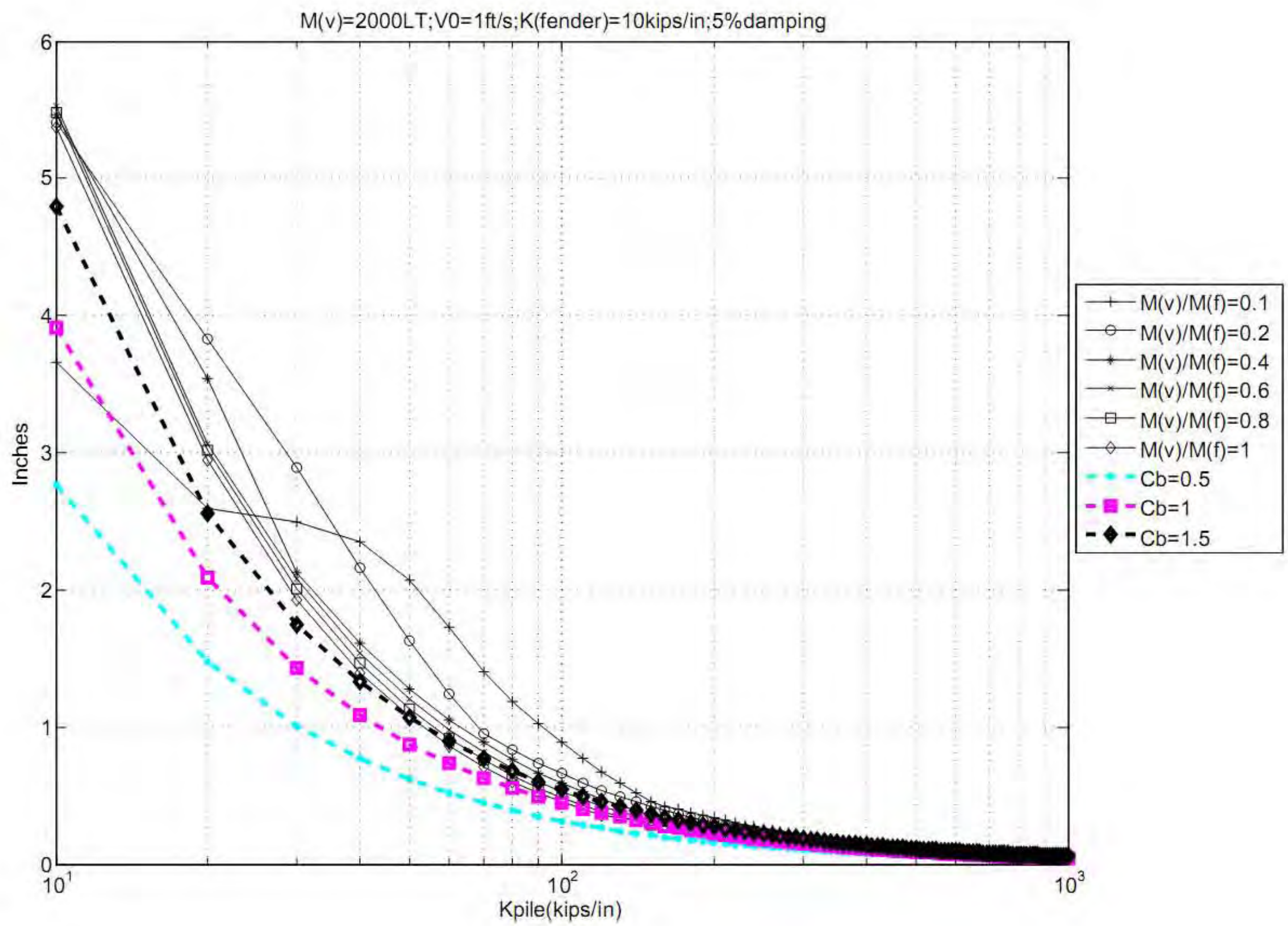
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
55
50
45
40
35
30
25
20
15
10
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.43 Reaction Force of the Piling System 1D-11a



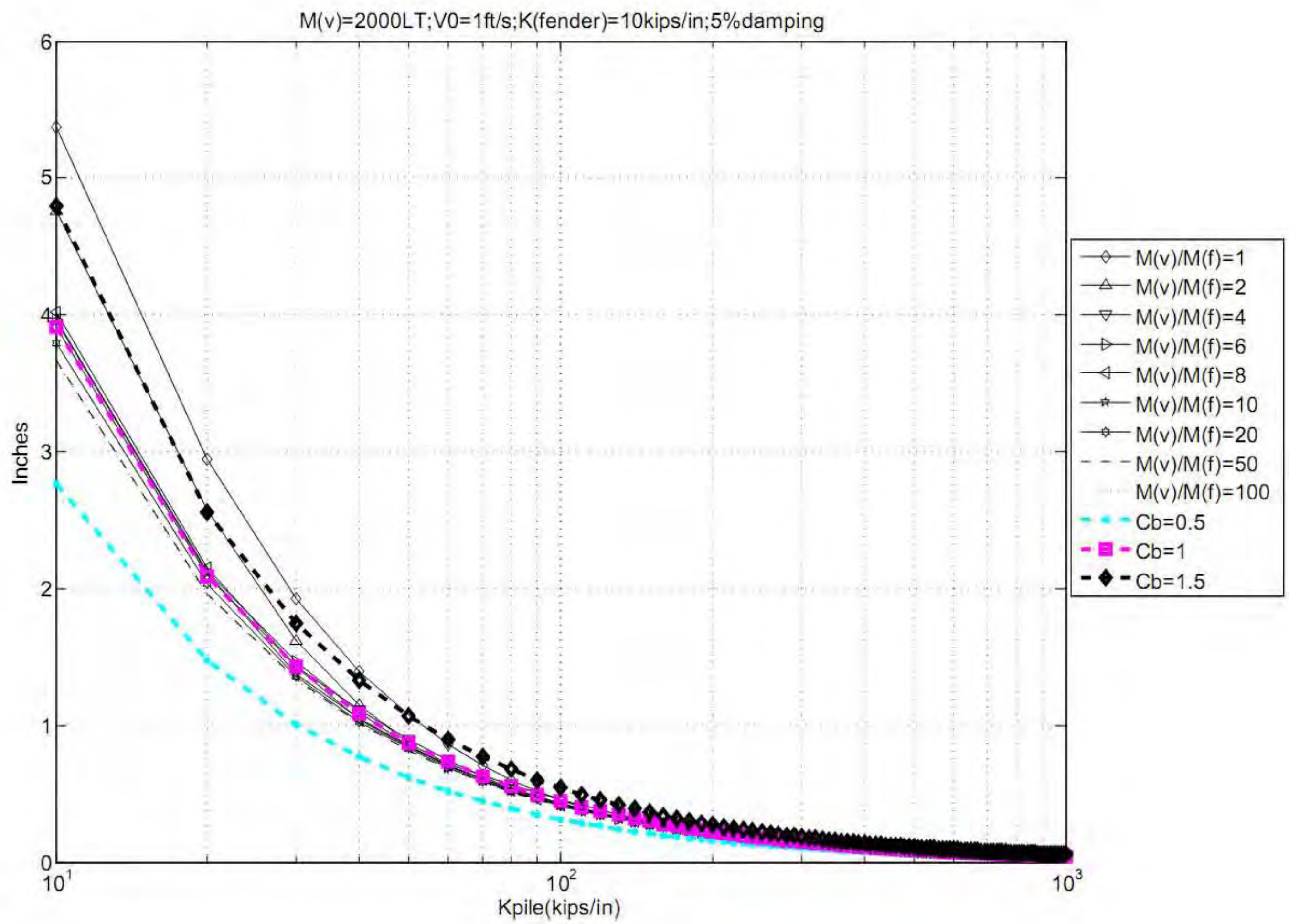
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
30
28
26
24
22
20
18
16
14
12
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.44 Reaction Force of the Piling System 1D-11b



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.45 Displacement of the Piling System 1D-12a



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
0
1
2
3
4
5
6
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.46 Displacement of the Piling System 1D-12b

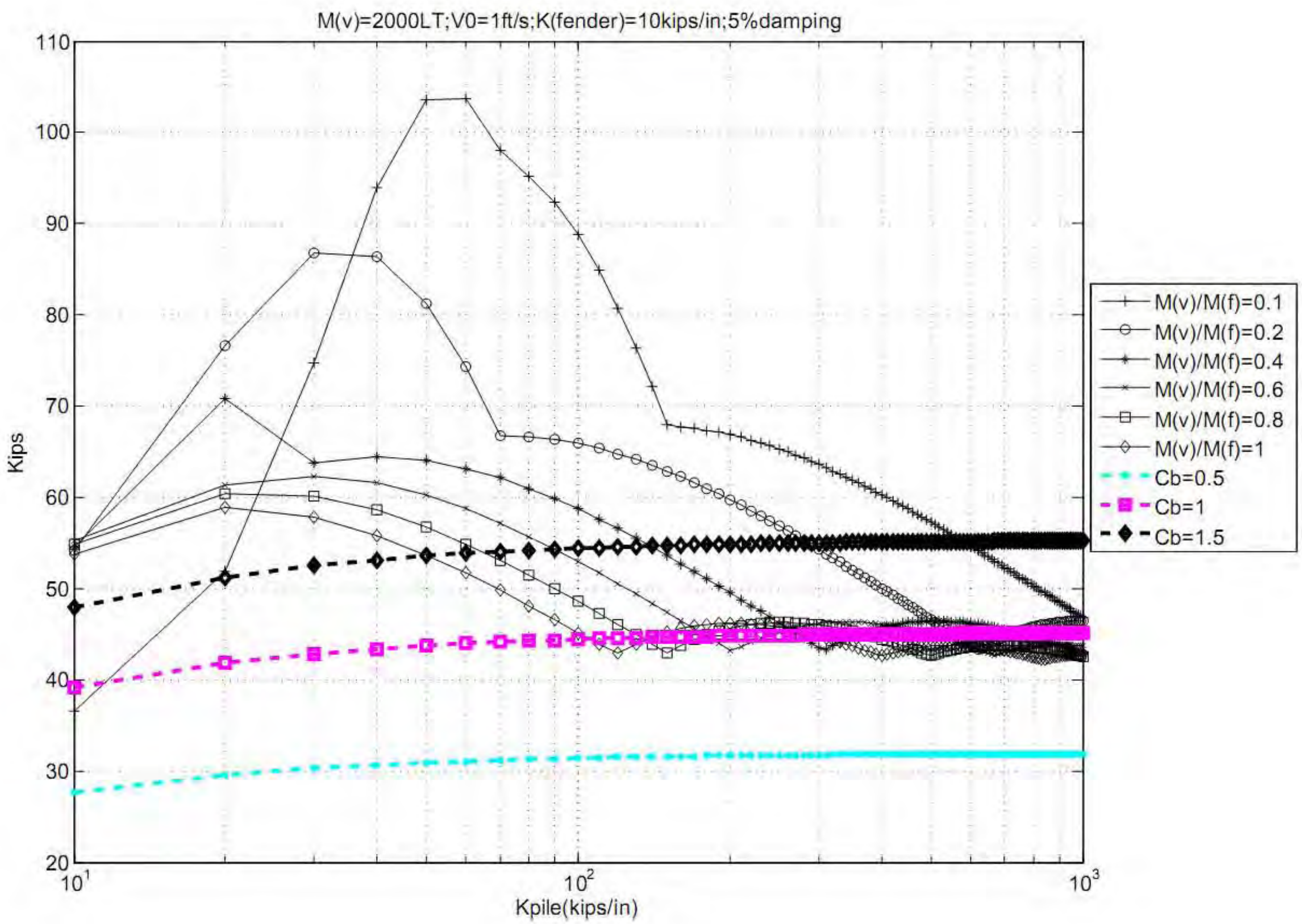

M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
110
100
90
80
70
60
50
40
30
20
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.47 Reaction Force of the Piling System 1D-12a

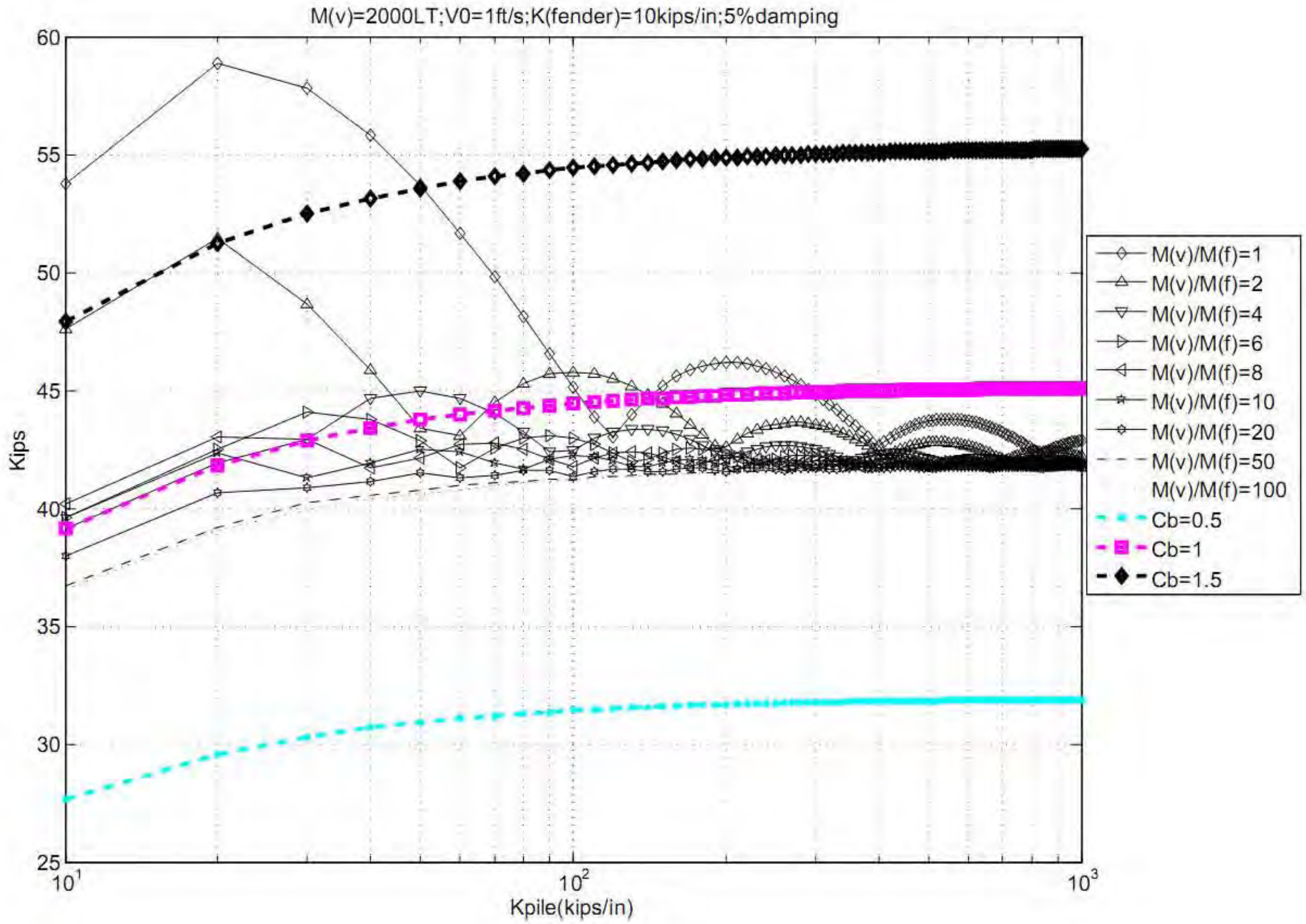

M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.48 Reaction Force of the Piling System 1D-12b

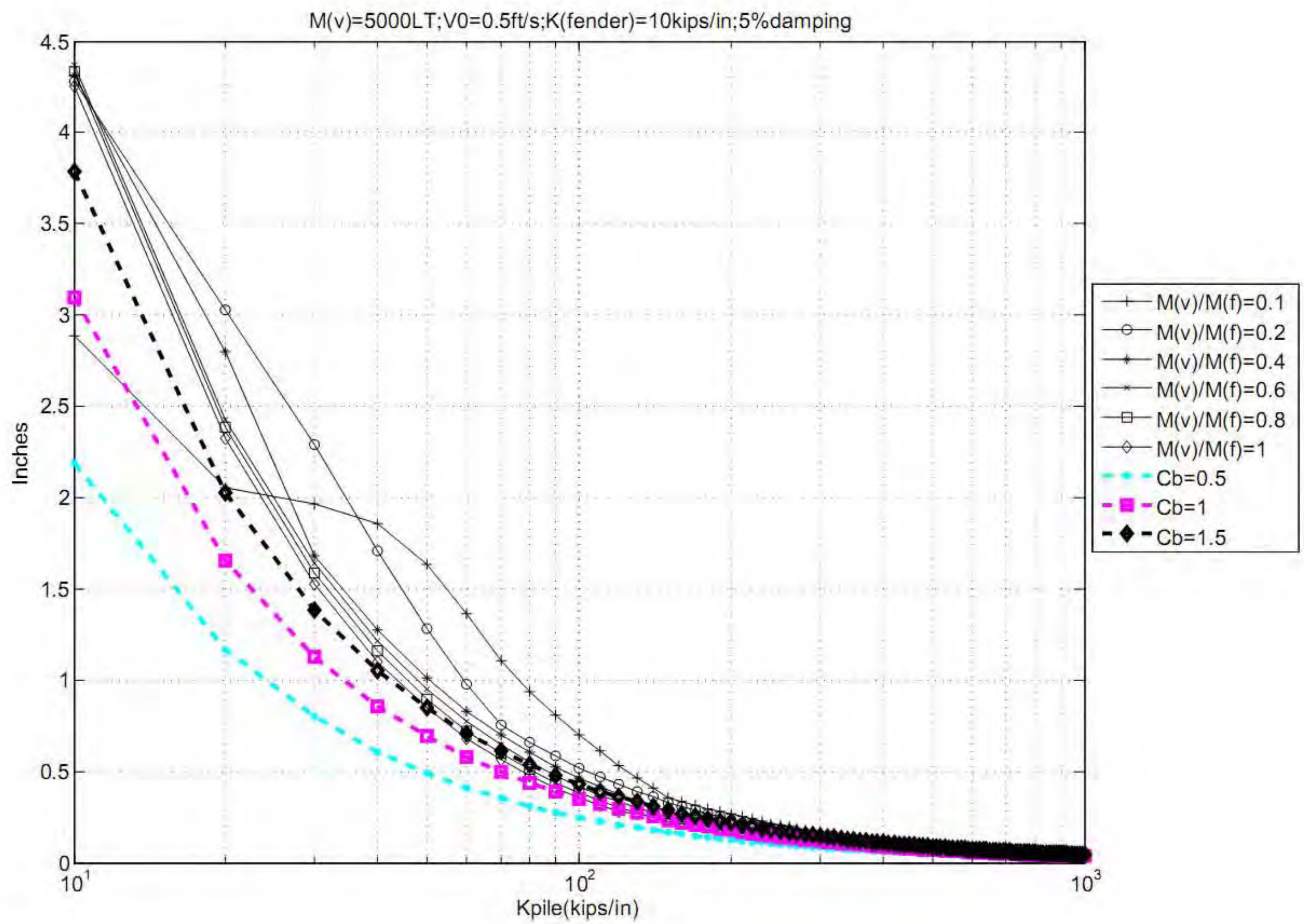

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.49 Displacement of the Piling System 1D-13a

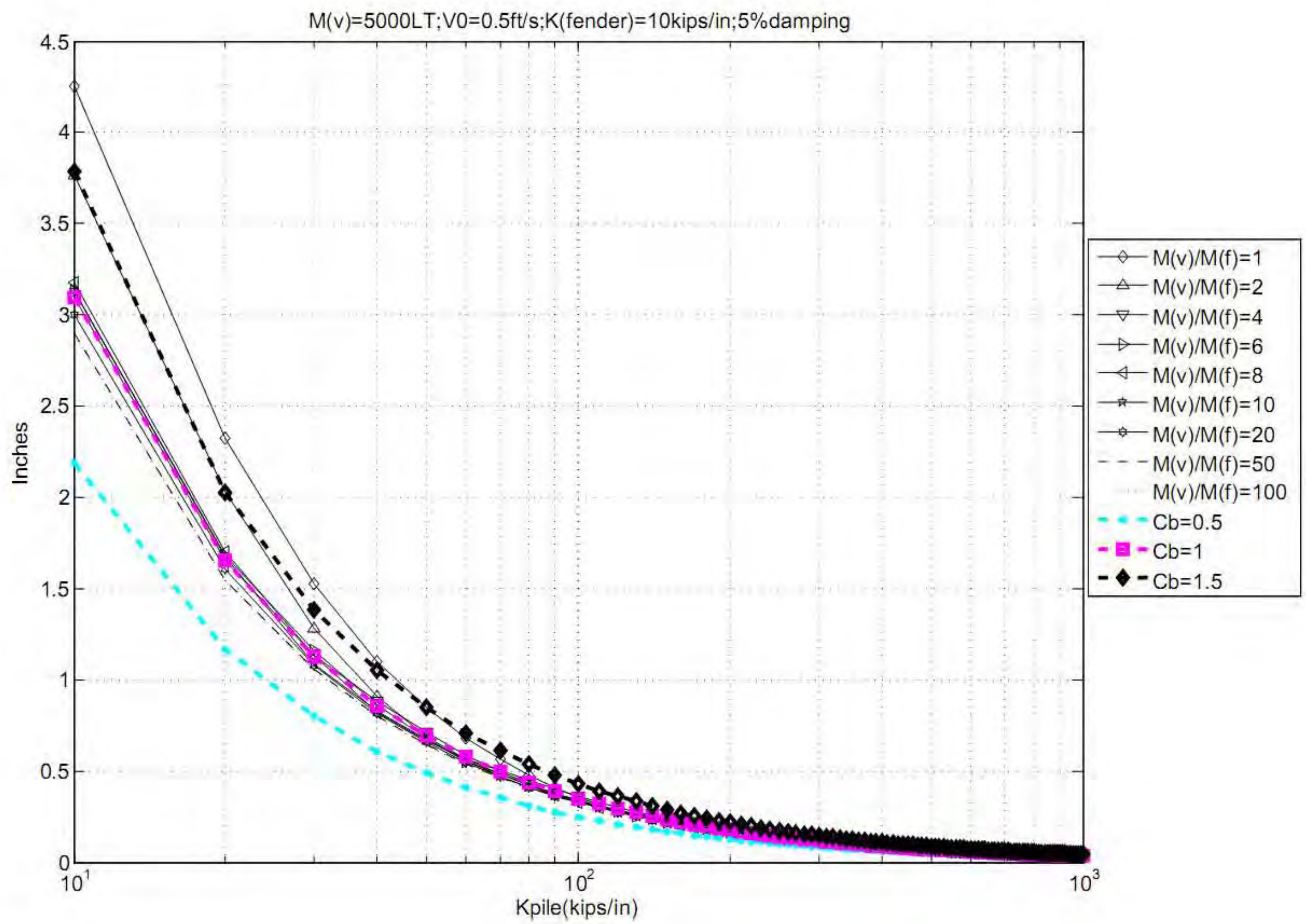

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.50 Displacement of the Piling System 1D-13b

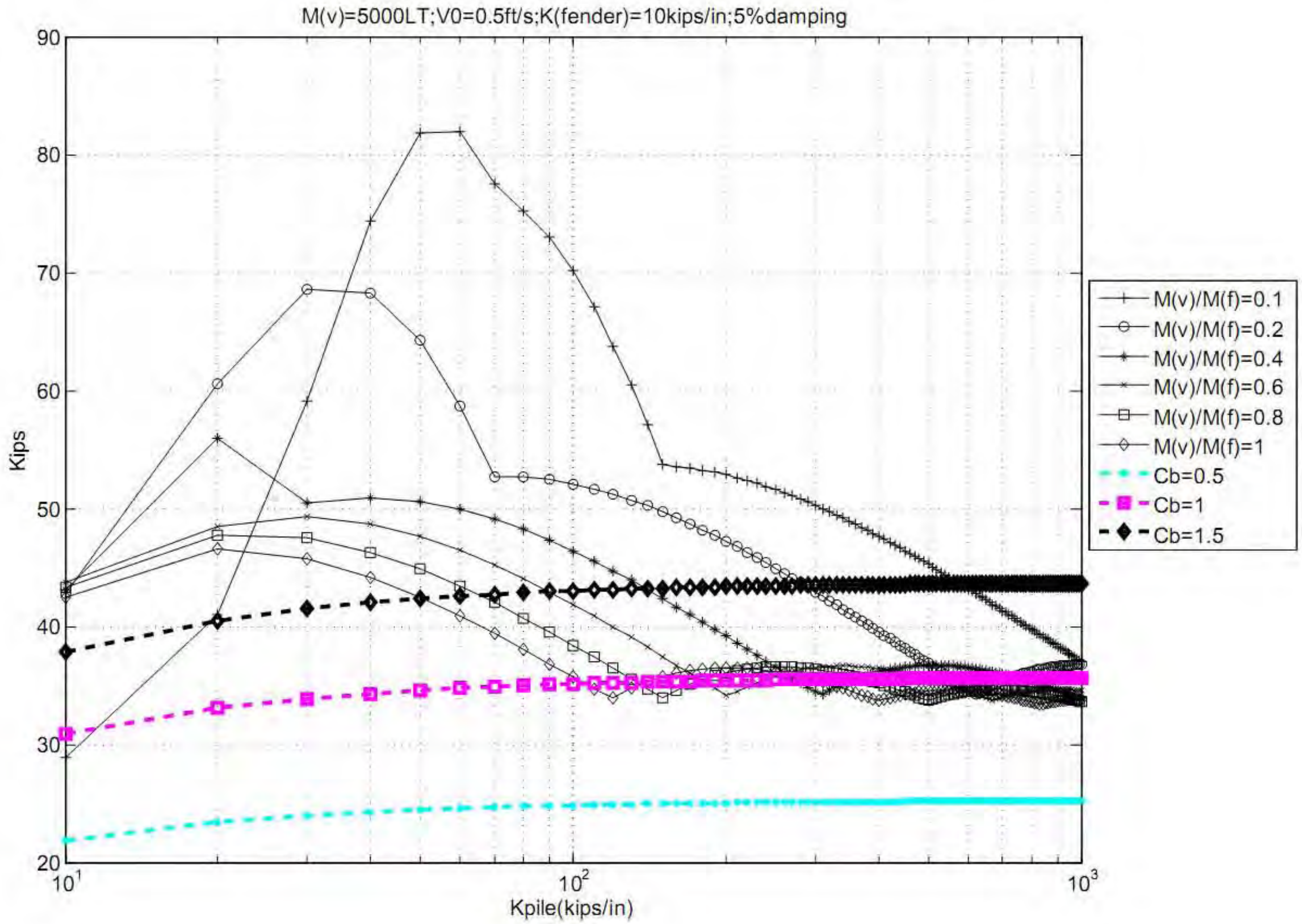

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
90
80
70
60
50
40
30
20
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.51 Reaction Force of the Piling System 1D-13a

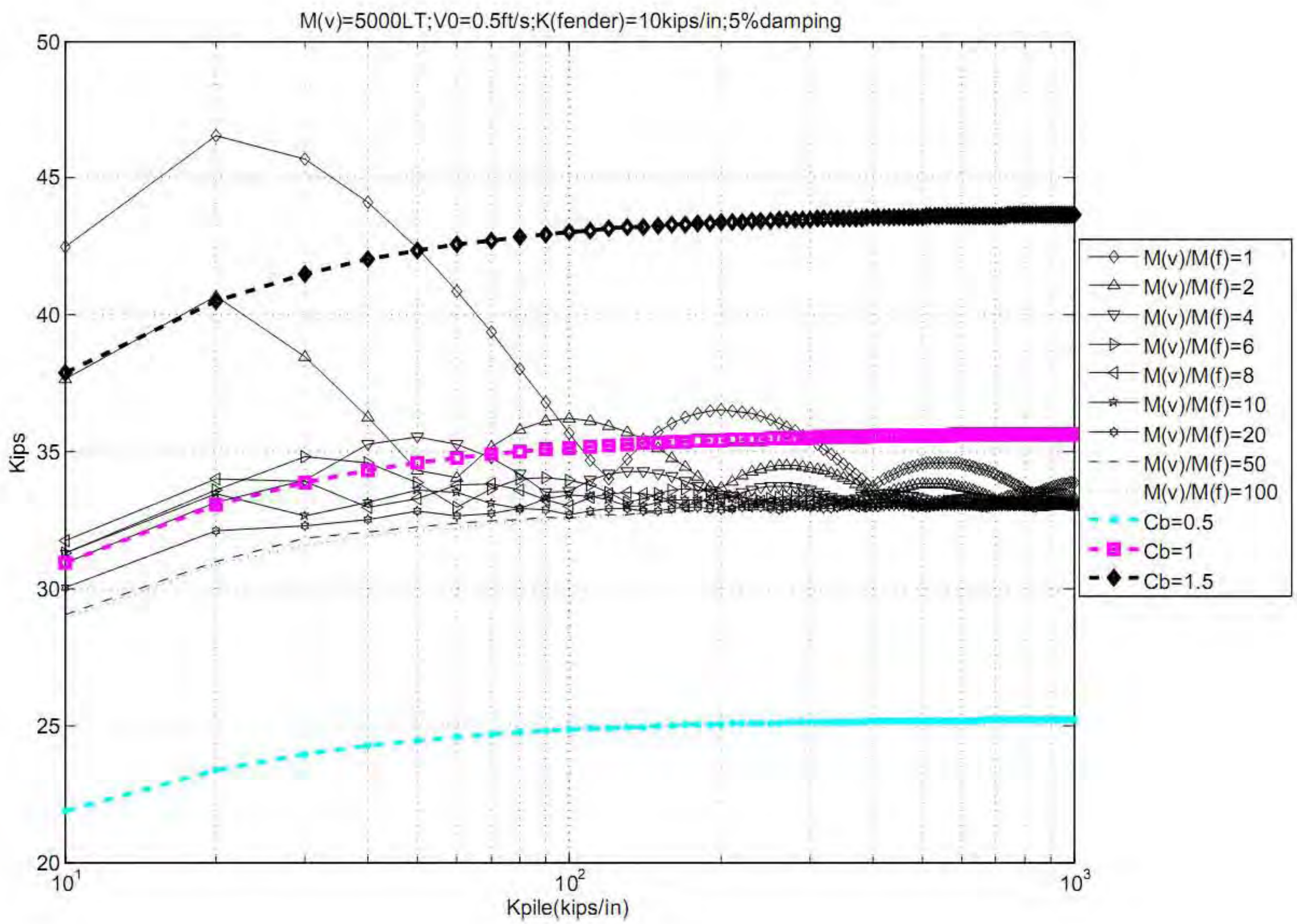
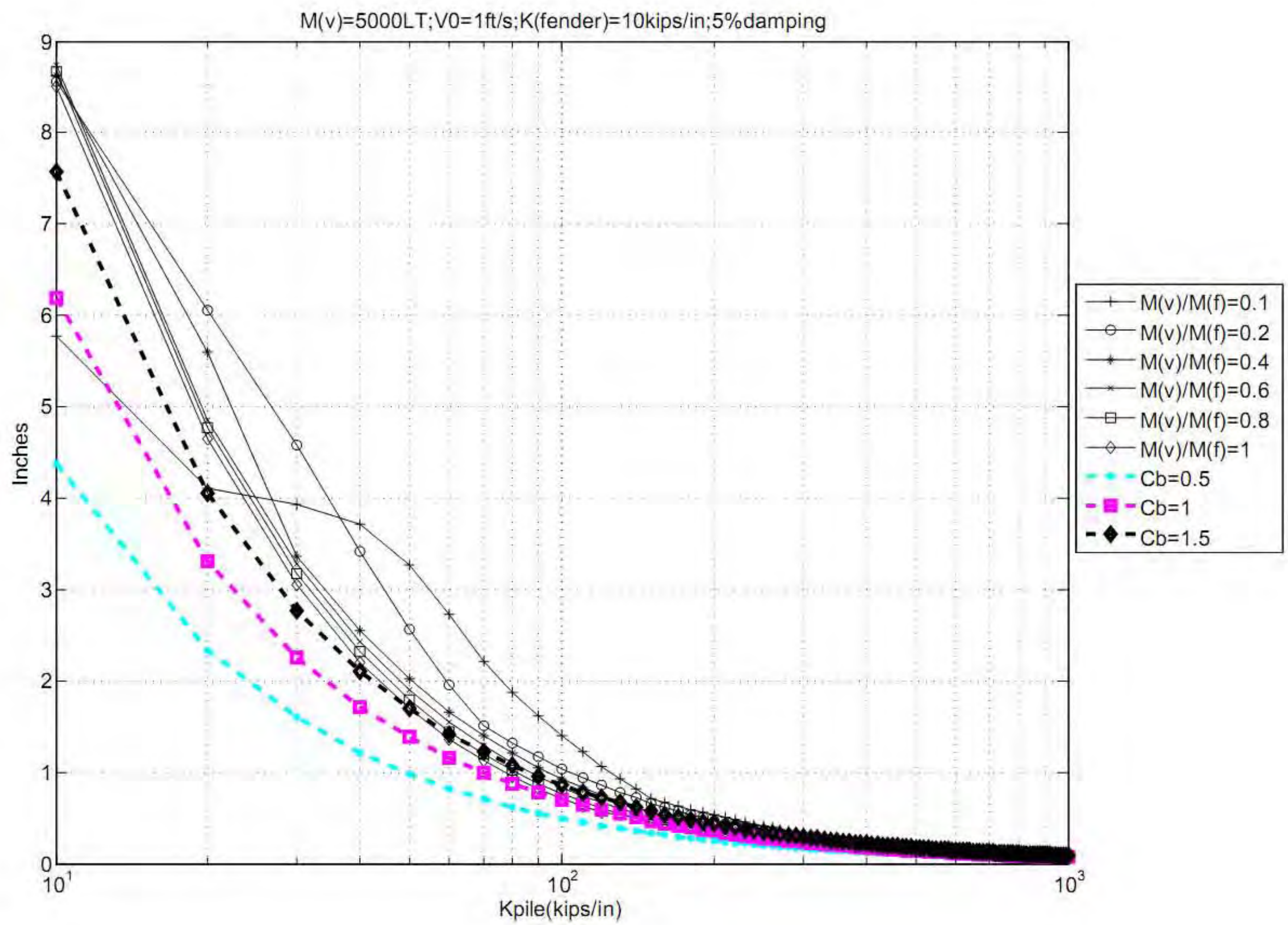
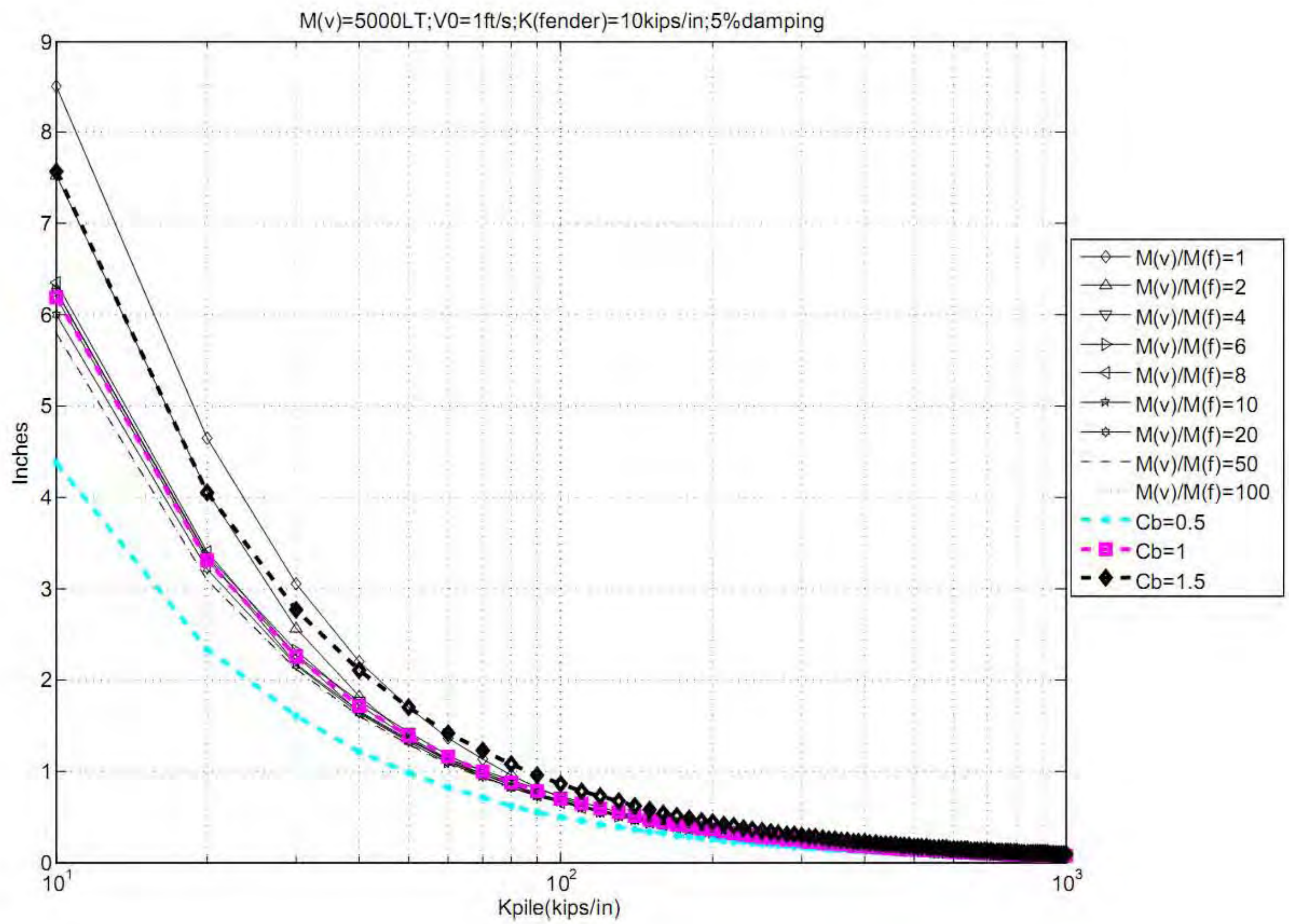

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
50
45
40
35
30
25
20
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.52 Reaction Force of the Piling System 1D-13b



M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.53 Displacement of the Piling System 1D-14a



M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
0
1
2
3
4
5
6
7
8
9
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.54 Displacement of the Piling System 1D-14b

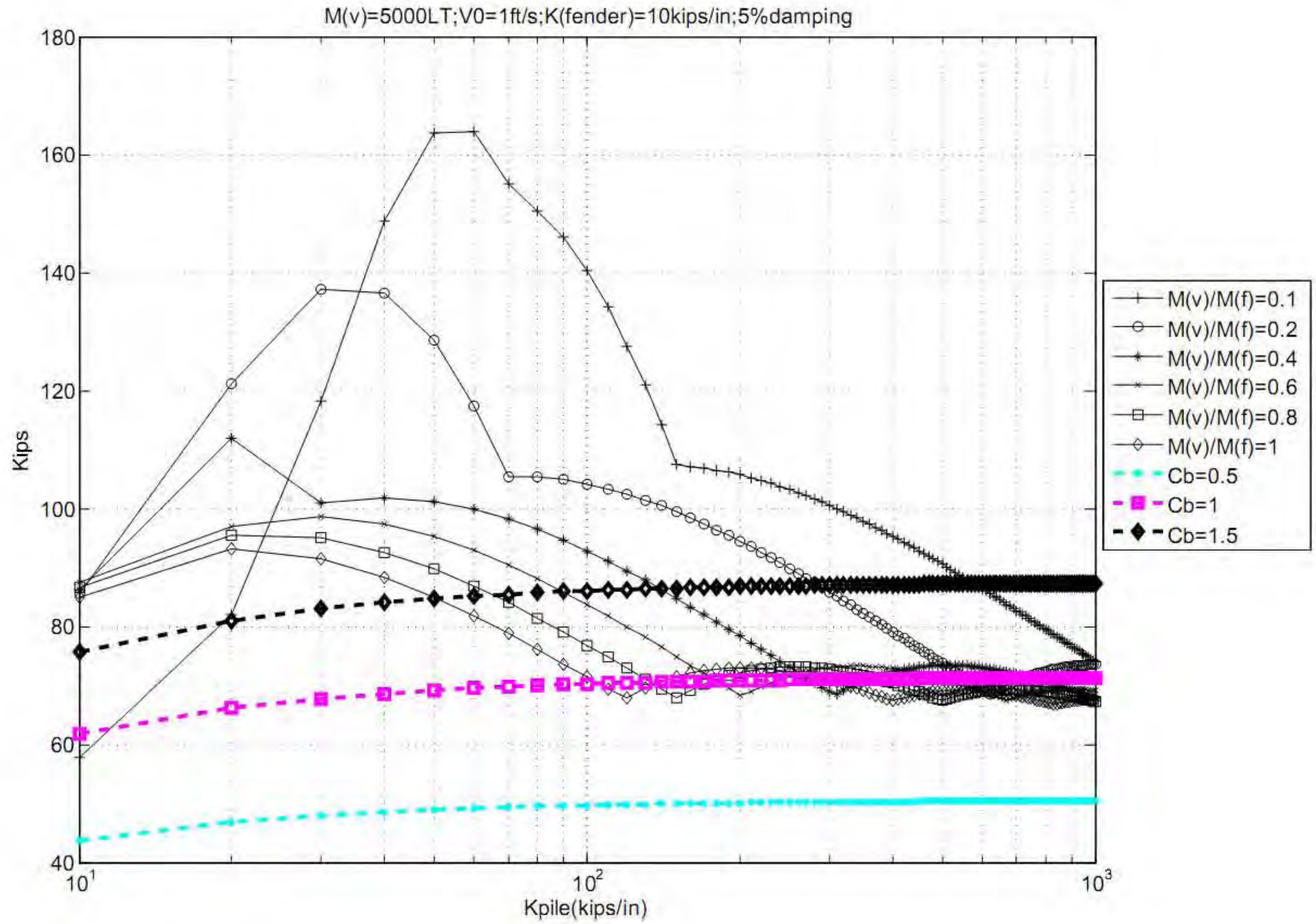
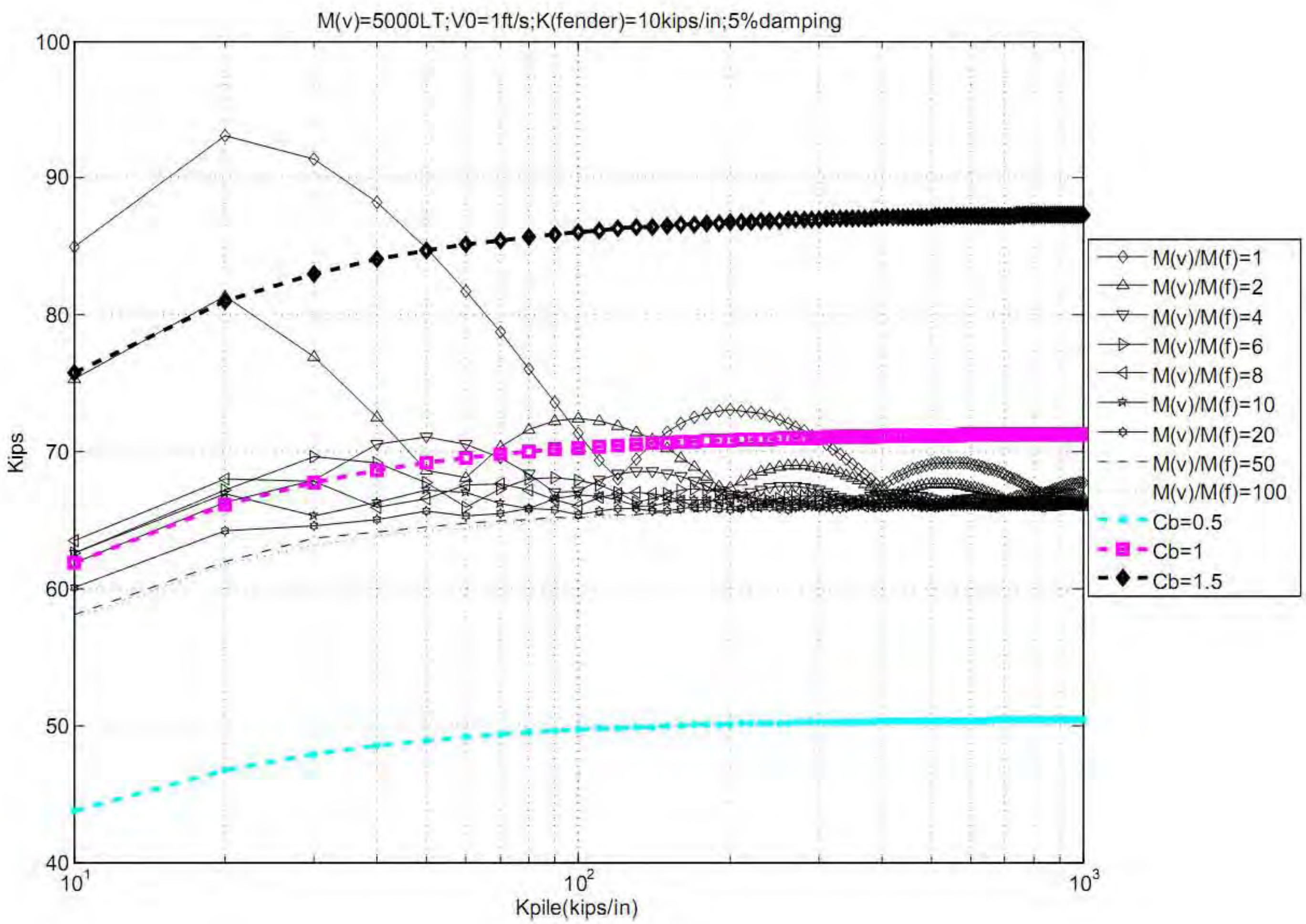
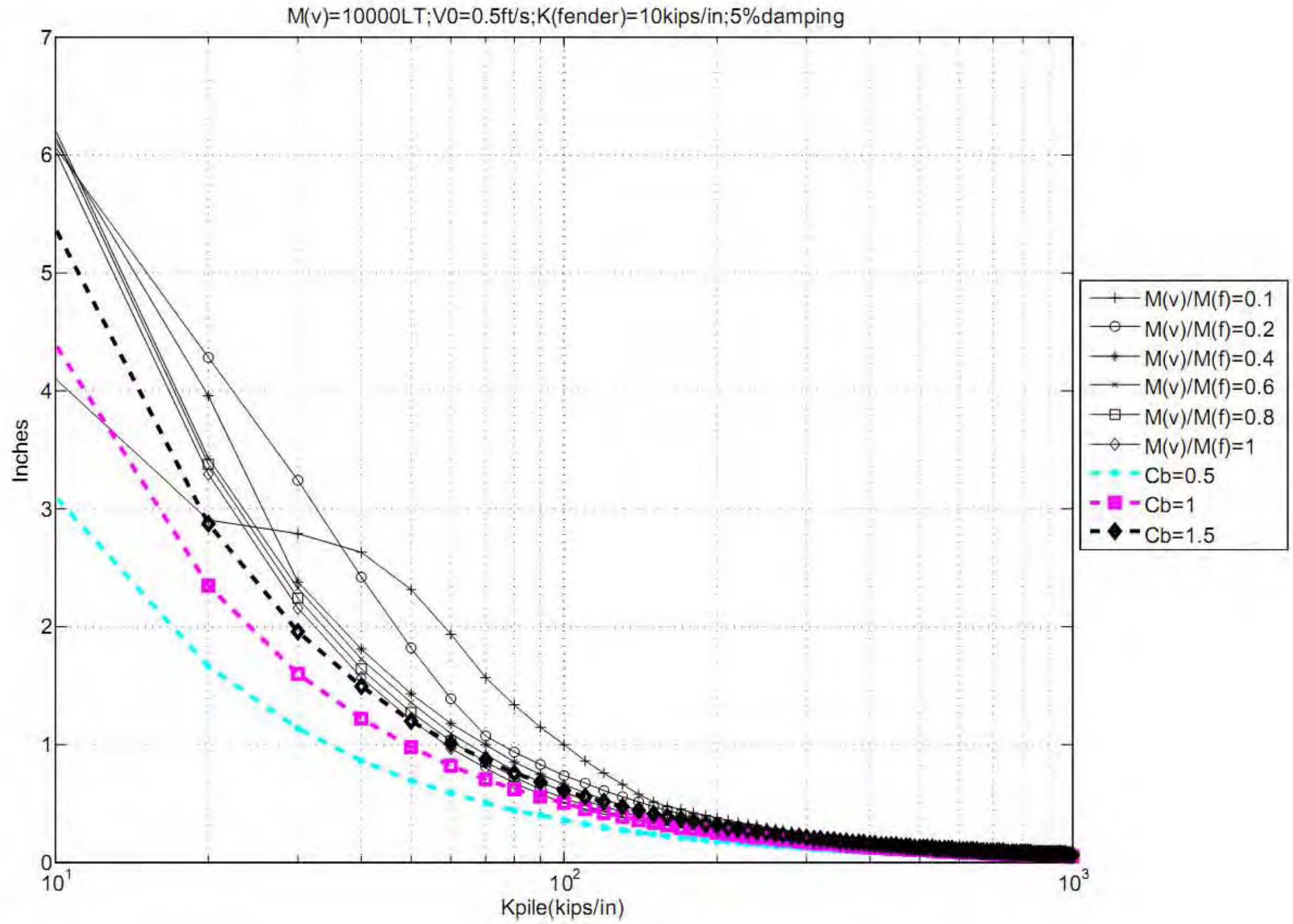

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
180
160
140
120
100
80
60
40
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.55 Reaction Force of the Piling System 1D-14a



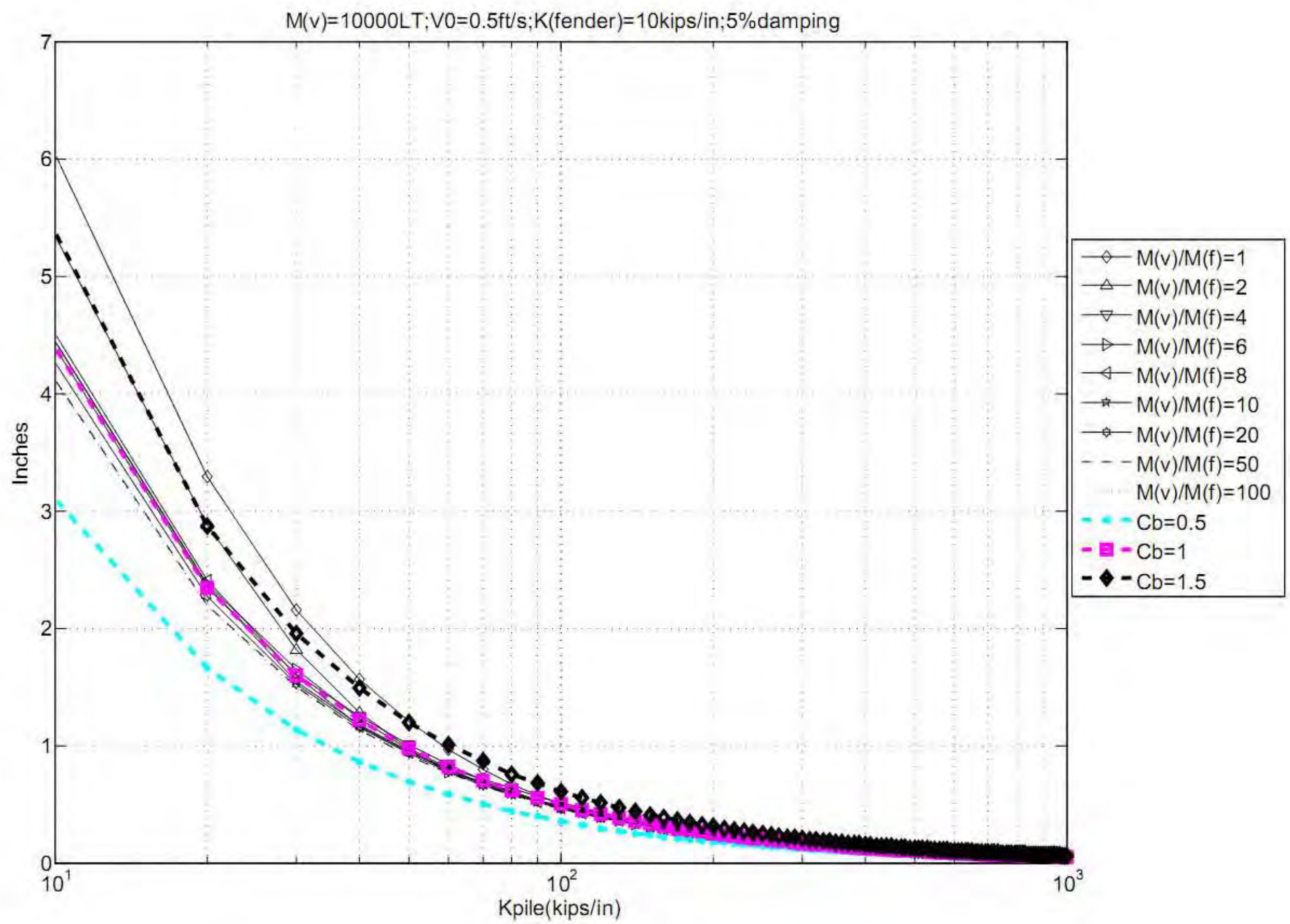
M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.56 Reaction Force of the Piling System 1D-14b



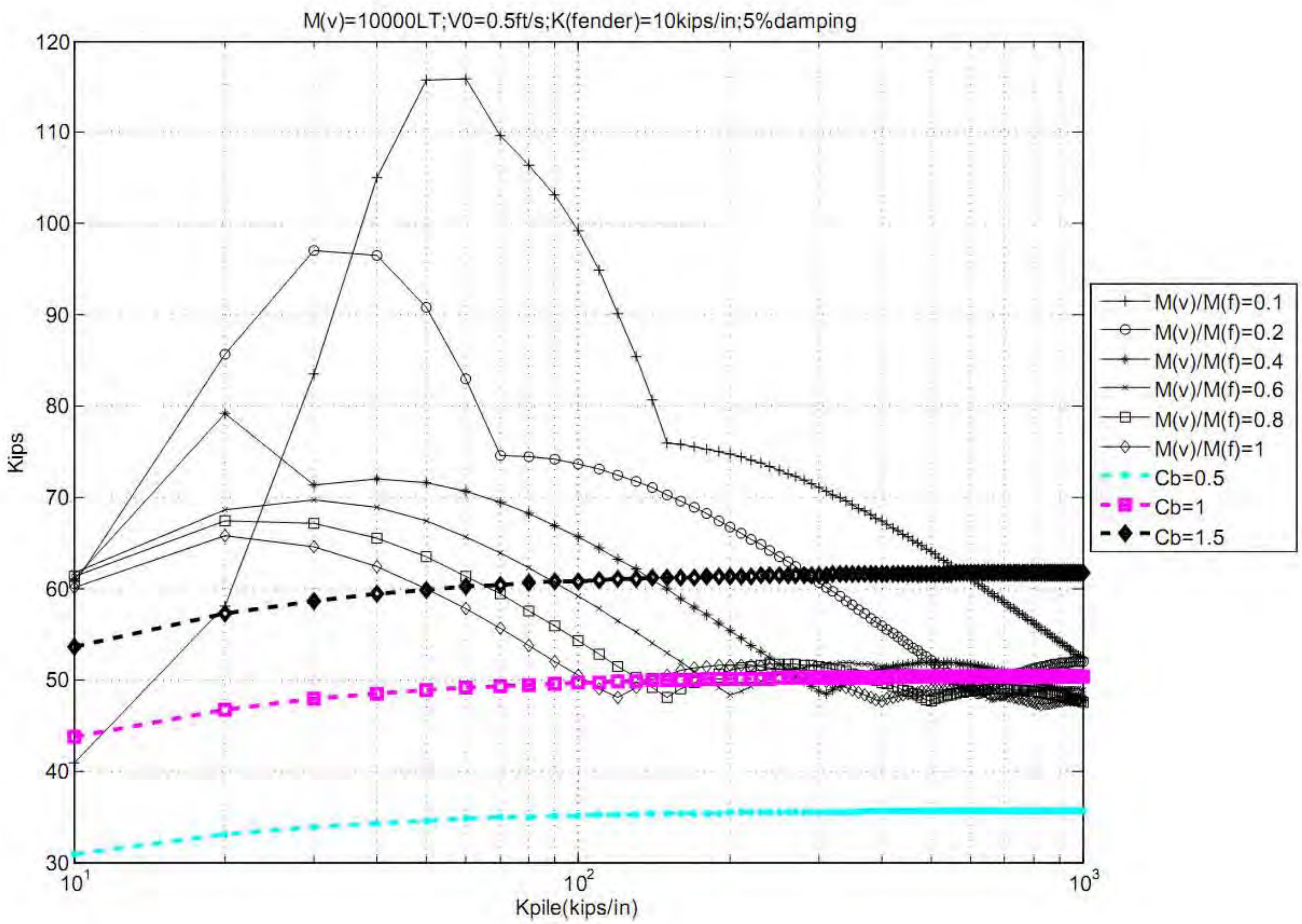
M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.57 Displacement of the Piling System 1D-15a



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.58 Displacement of the Piling System 1D-15b



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.59 Reaction Force of the Piling System 1D-15a

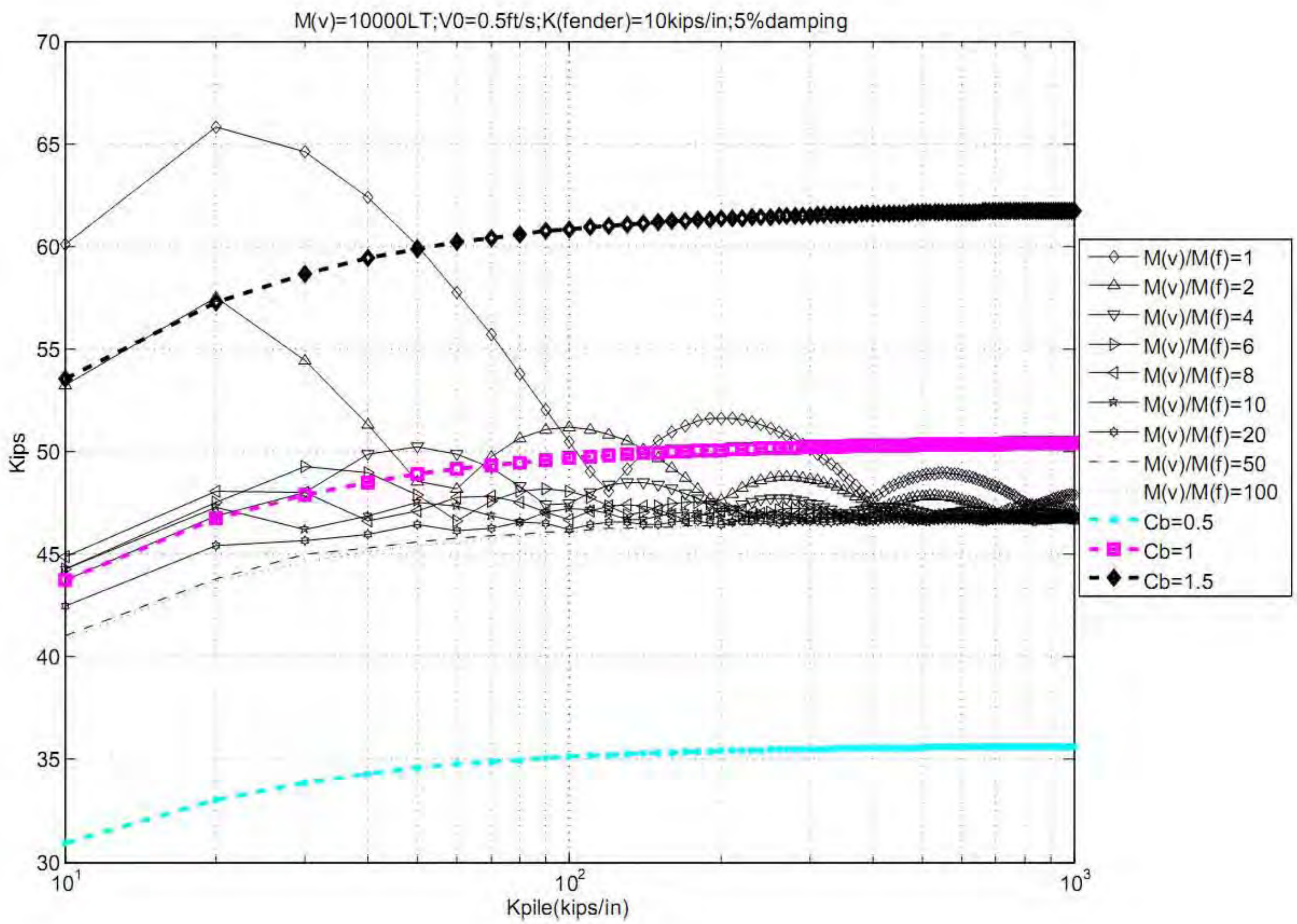

M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;5%damping
70
65
60
55
50
45
40
35
30
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.60 Reaction Force of the Piling System 1D-15b

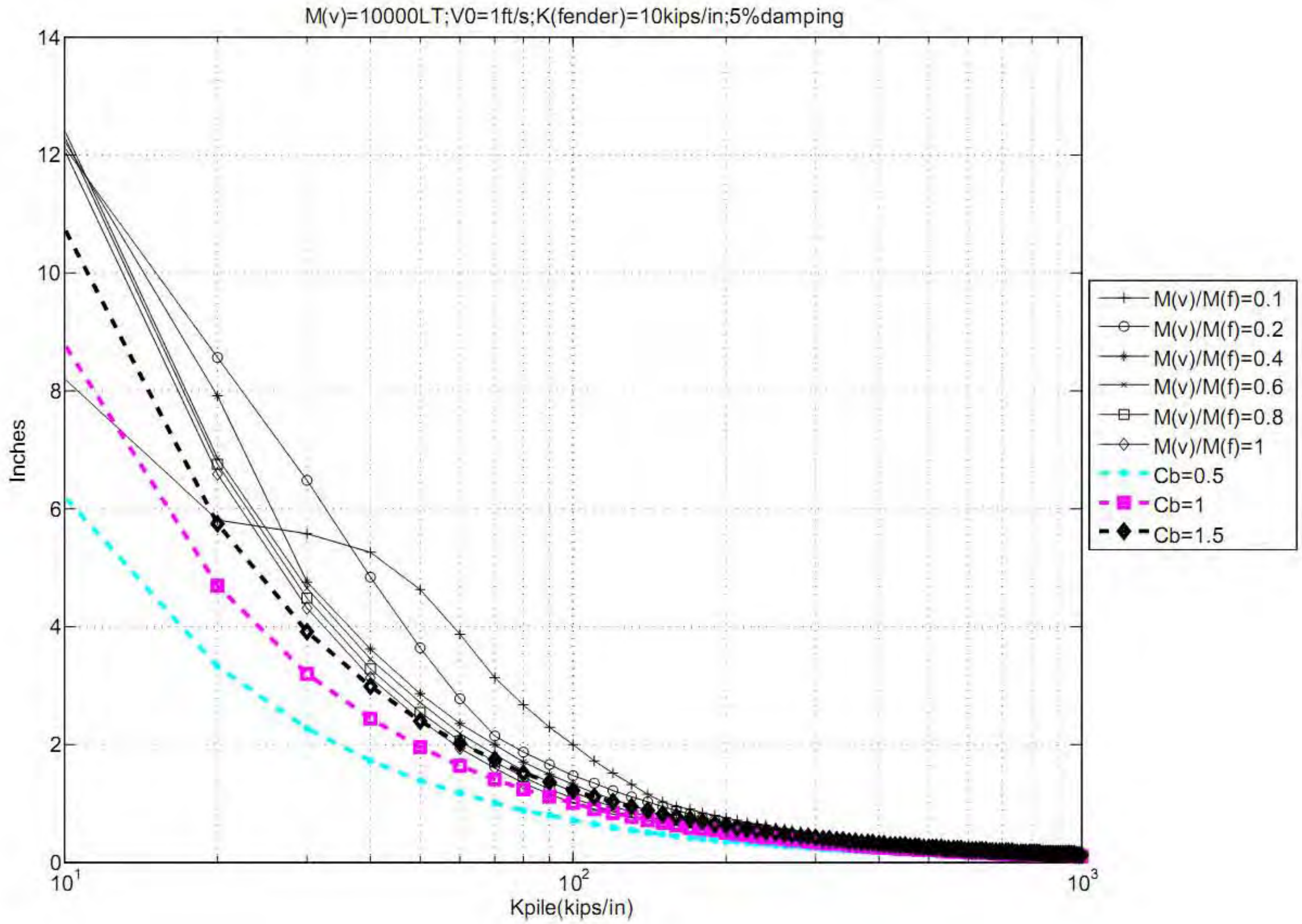

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
0
2
4
6
8
10
12
14
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.61 Displacement of the Piling System 1D-16a

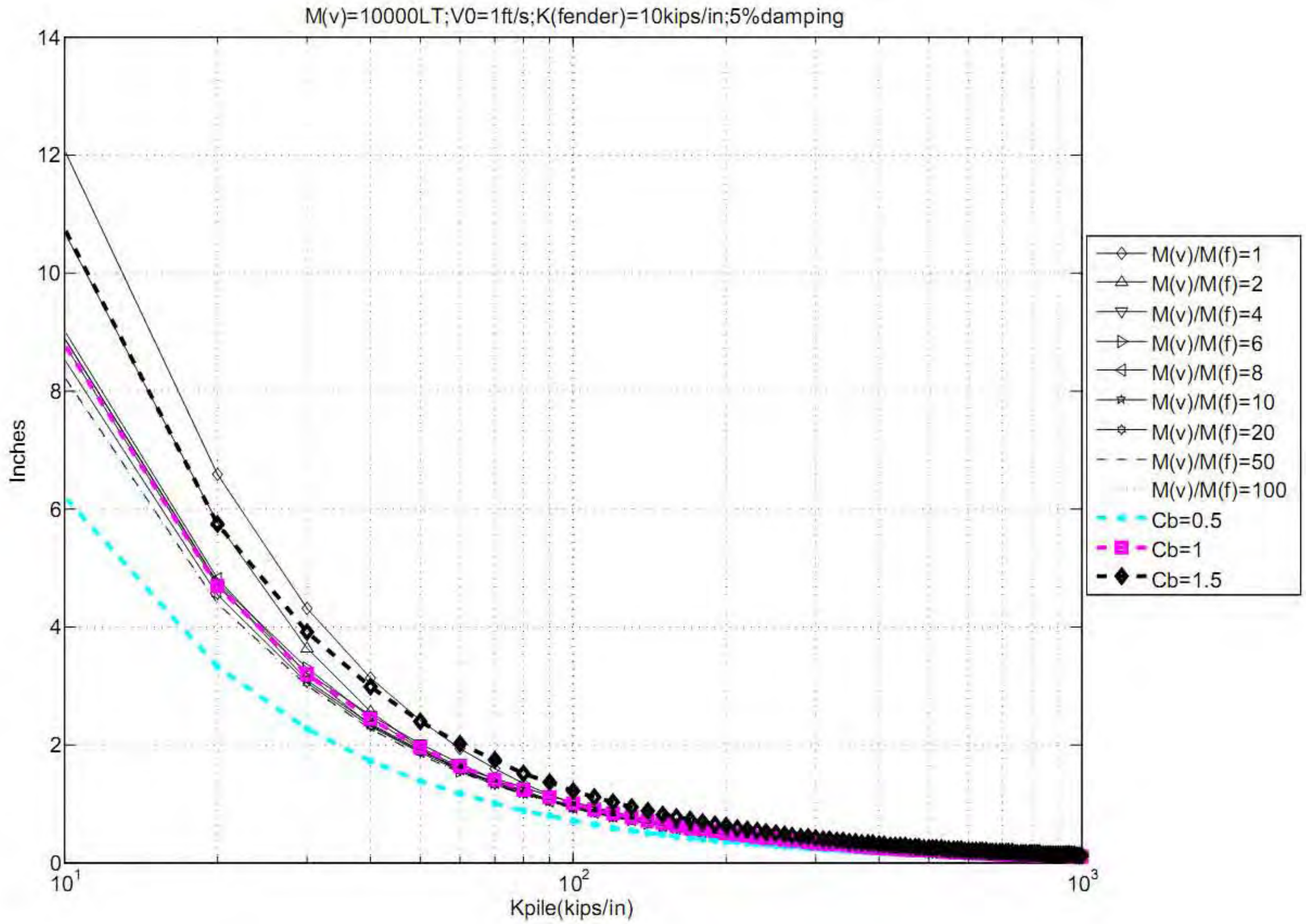
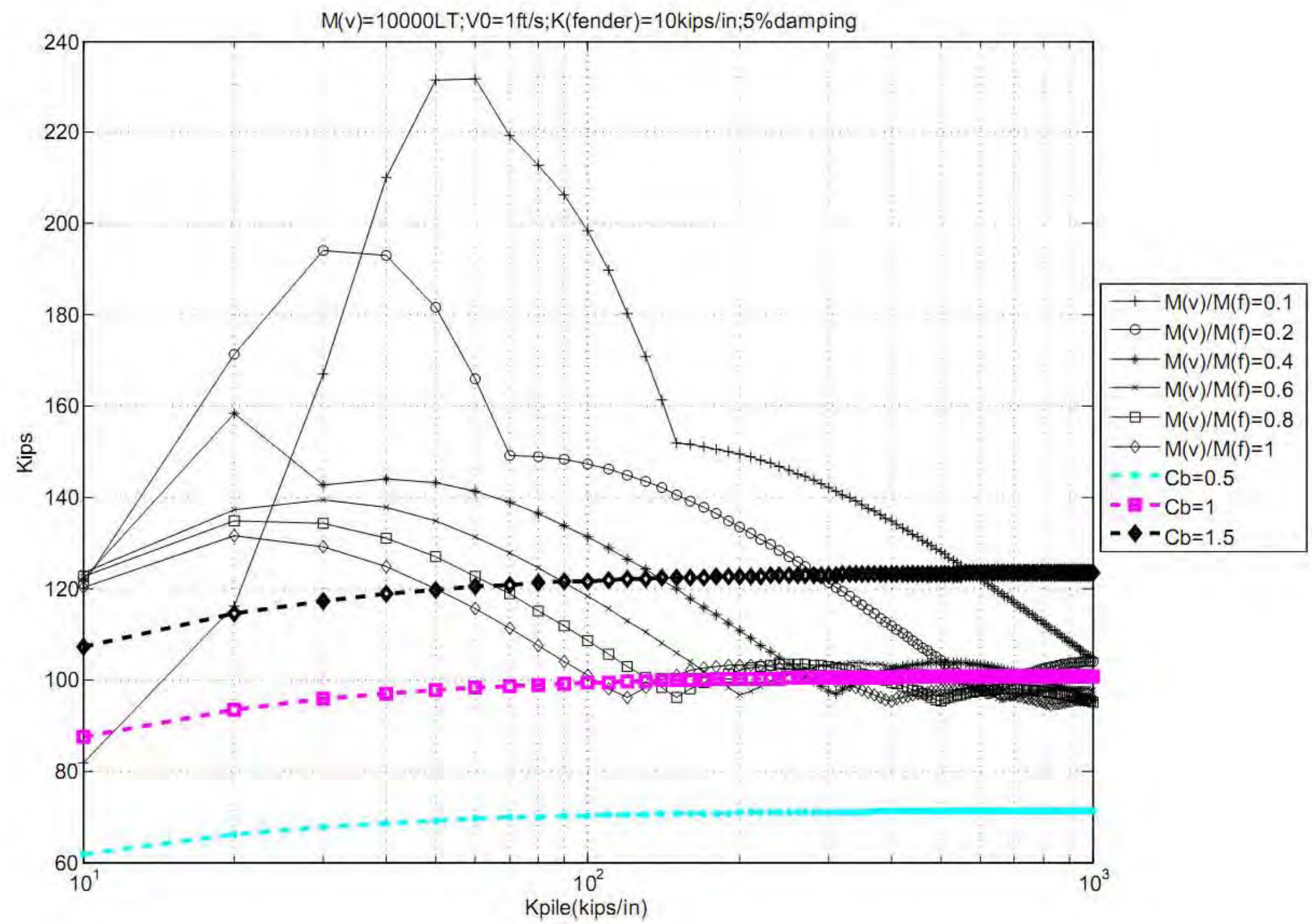
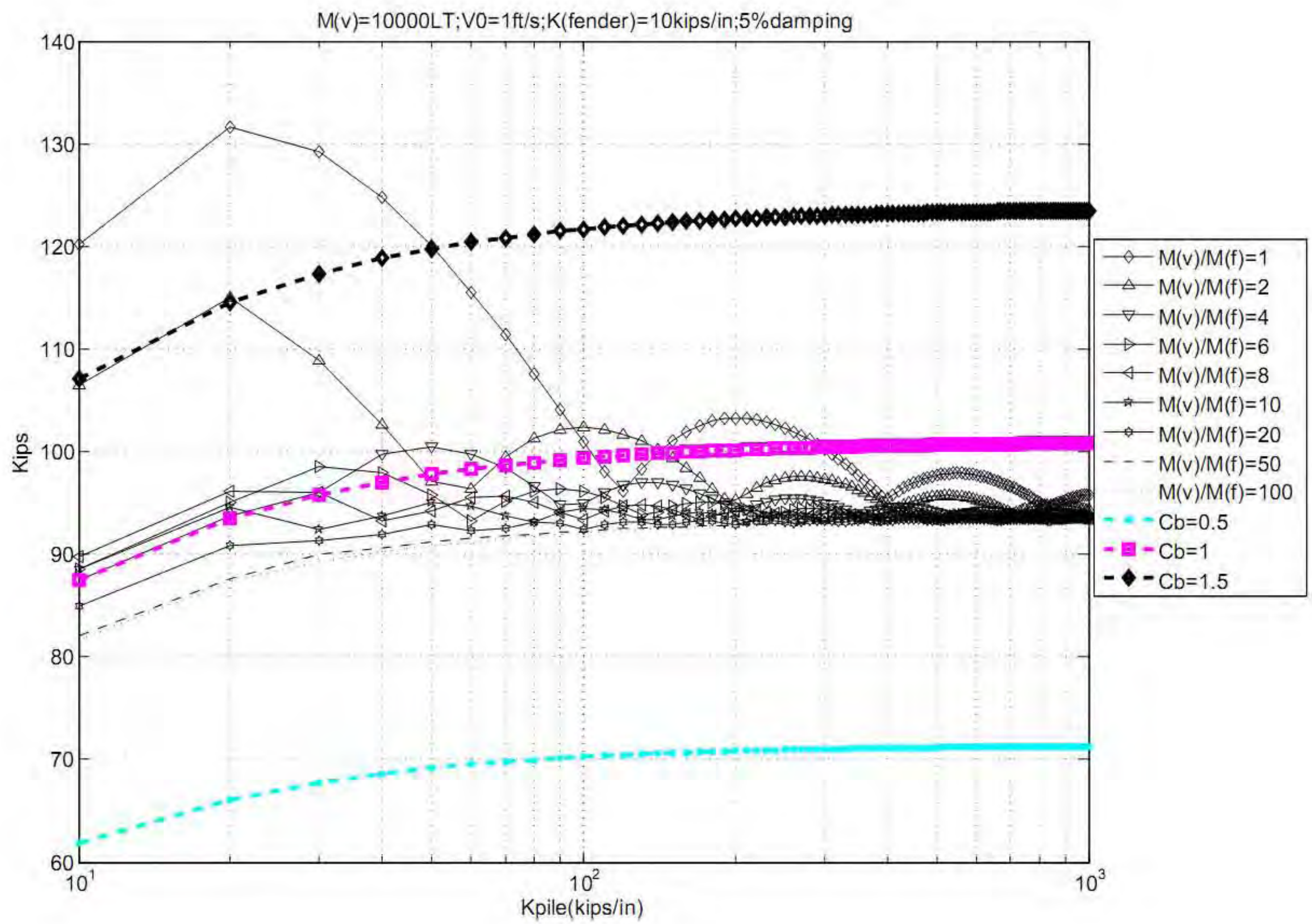

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.62 Displacement of the Piling System 1D-16b



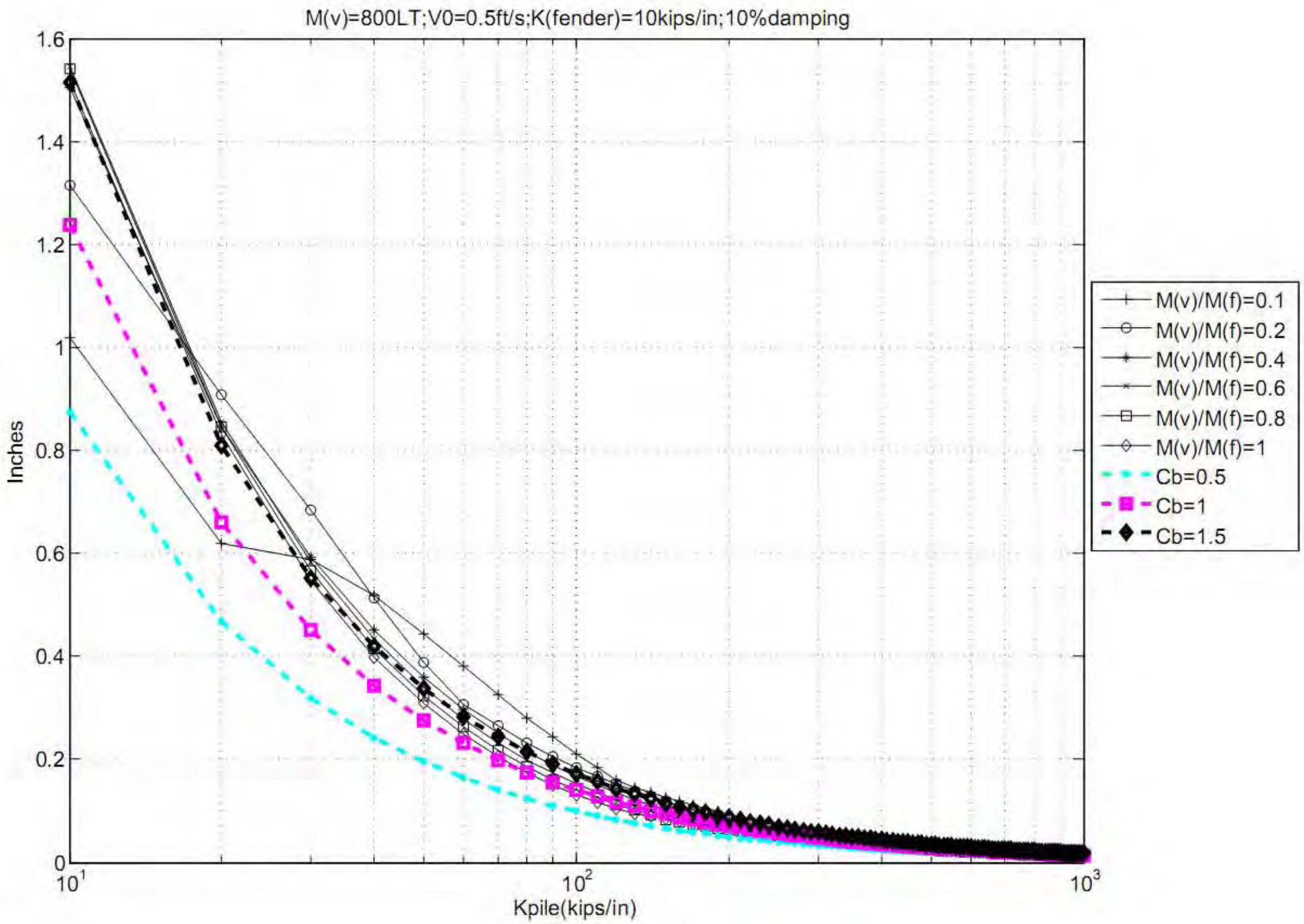
M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
240
220
200
180
160
140
120
100
80
60
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.63 Reaction Force of the Piling System 1D-16a



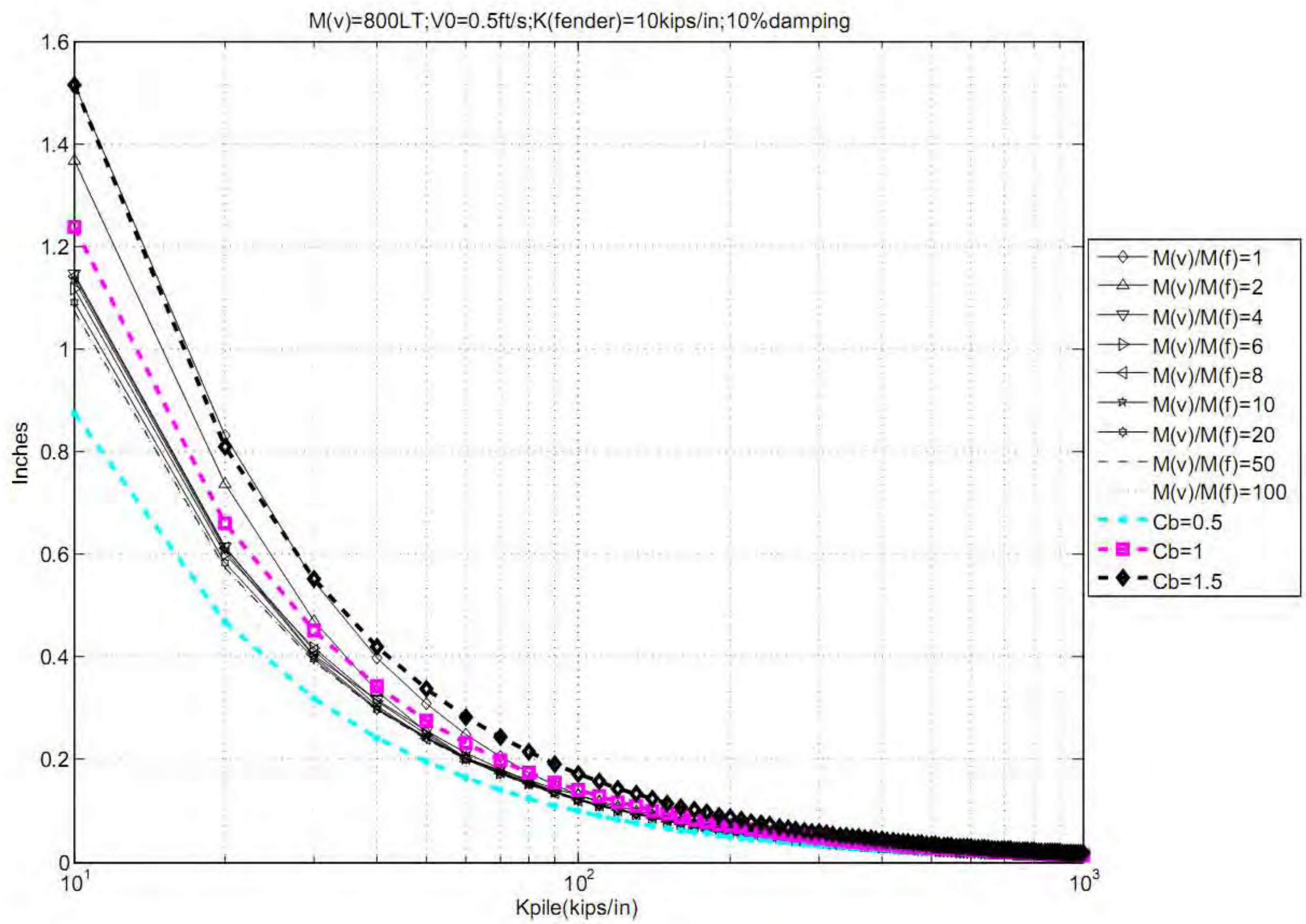
M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;5%damping
Kips
Kpile(kips/in)
140
130
120
110
100
90
80
70
60
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.64 Reaction Force of the Piling System 1D-16b



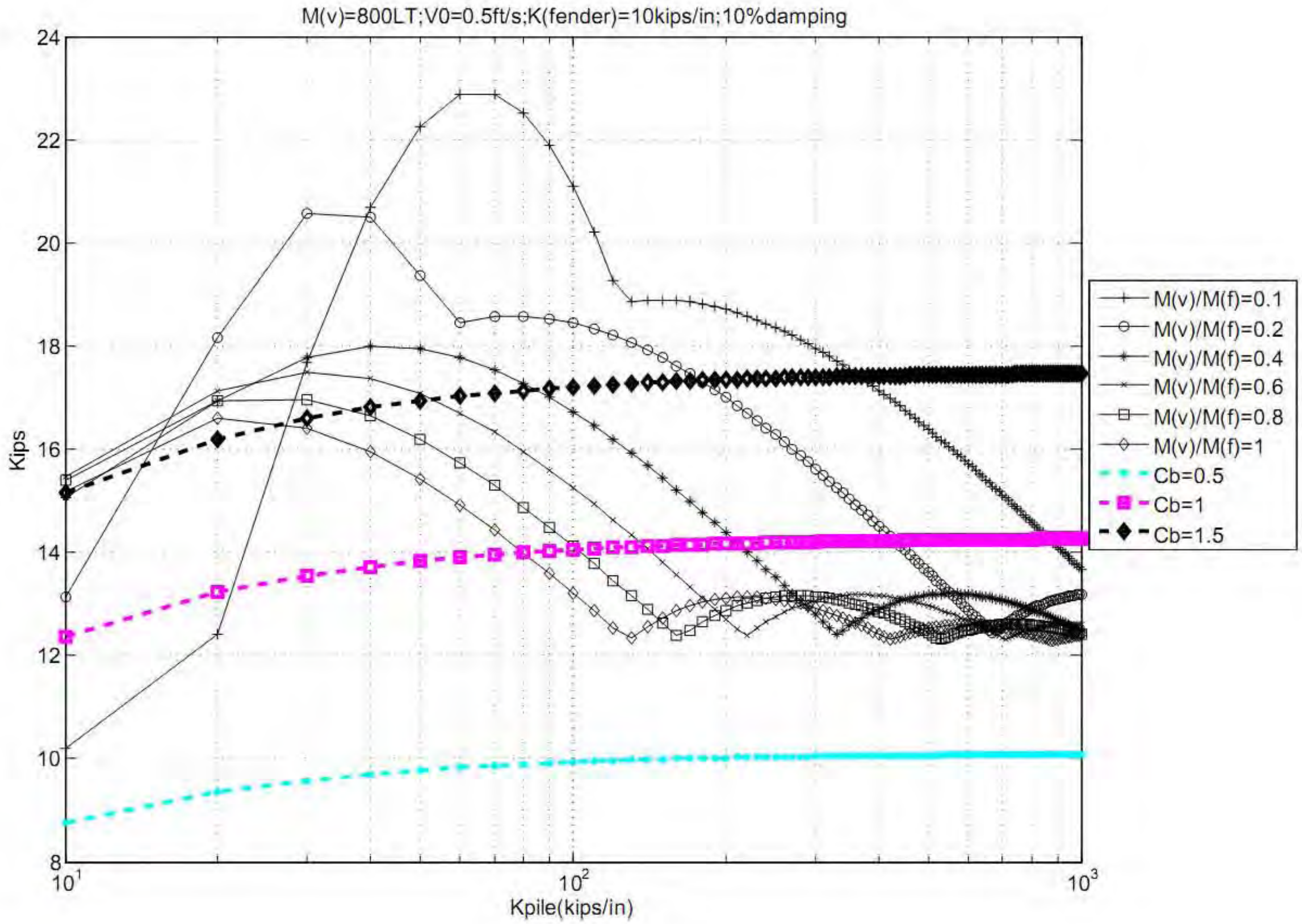
M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.65 Displacement of the Piling System 1D-17a



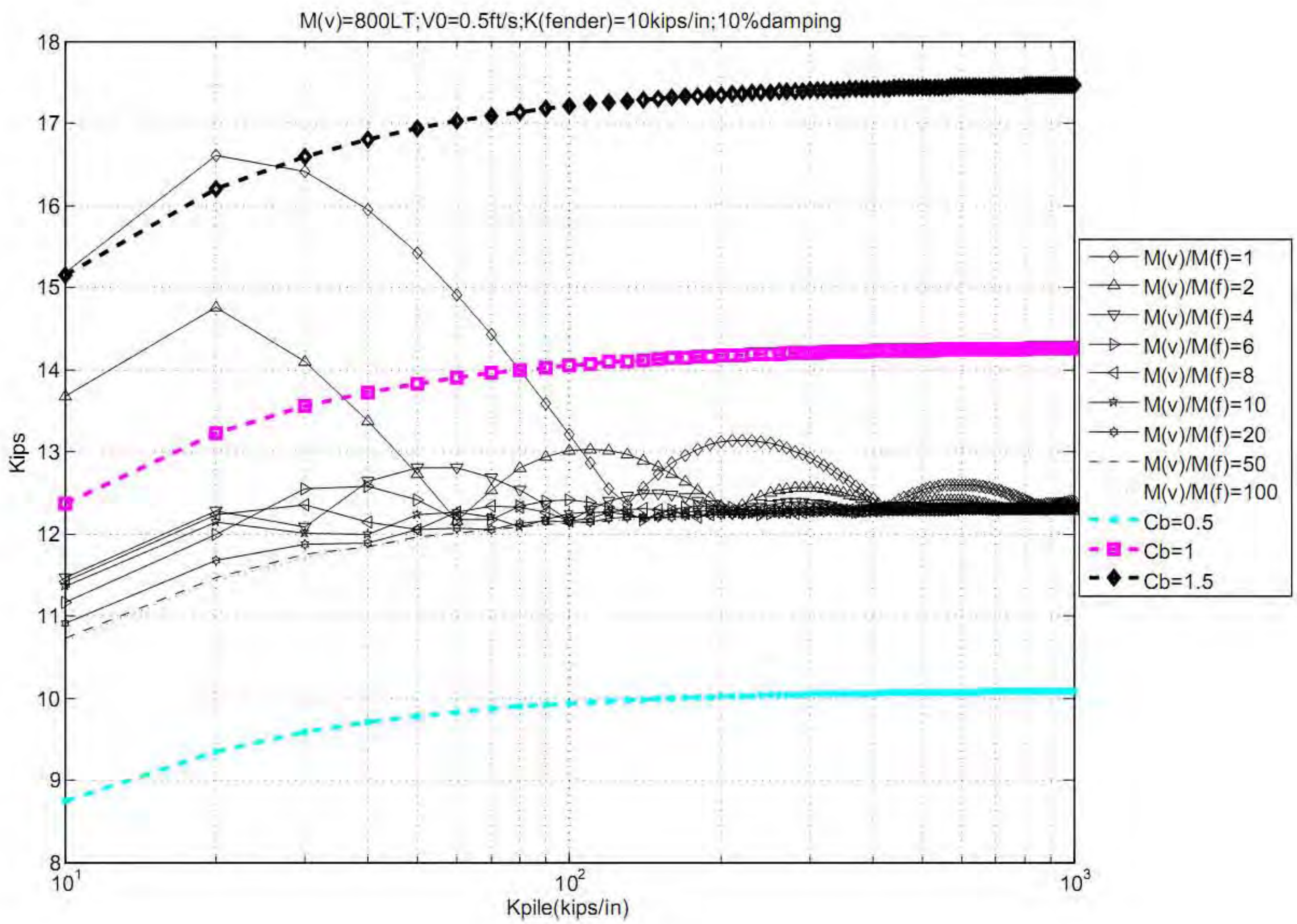
M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.66 Displacement of the Piling System 1D-17b



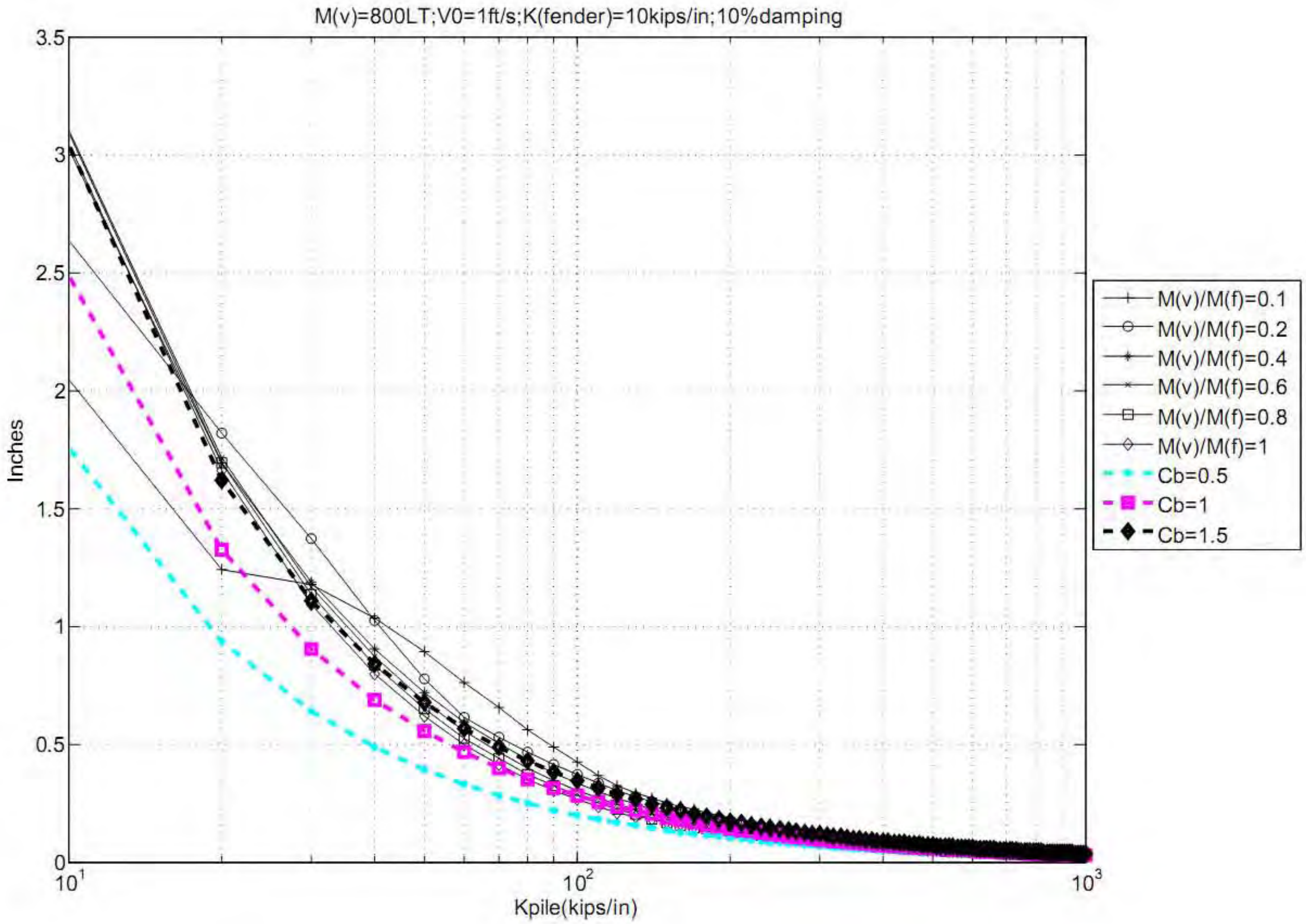
M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.67 Reaction Force of the Piling System 1D-17a



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.68 Reaction Force of the Piling System 1D-17b



M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.69 Displacement of the Piling System 1D-18a

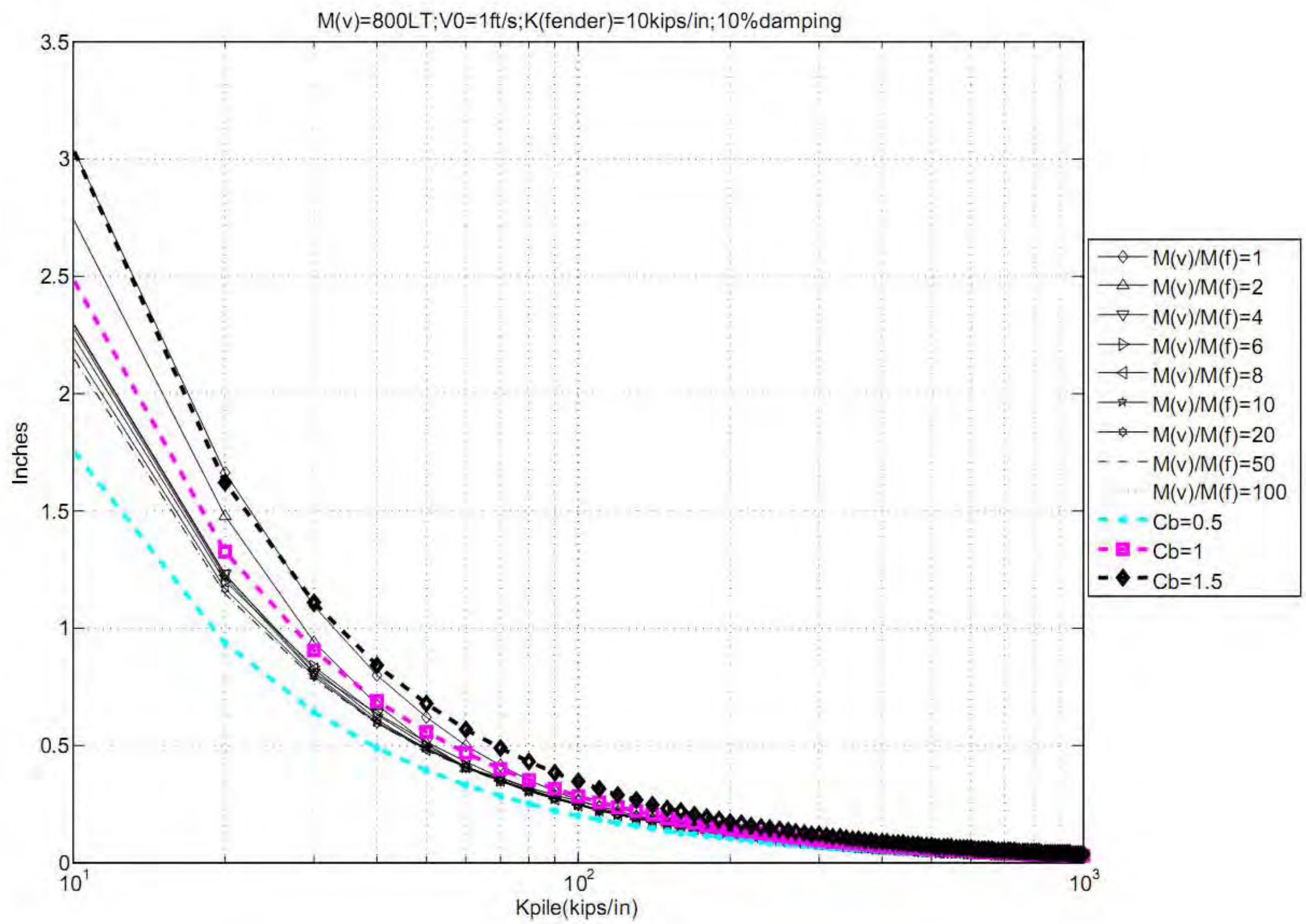

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;10%damping
3.5
3
2.5
2
1.5
1
0.5
0
Inches
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.70 Displacement of the Piling System 1D-18b

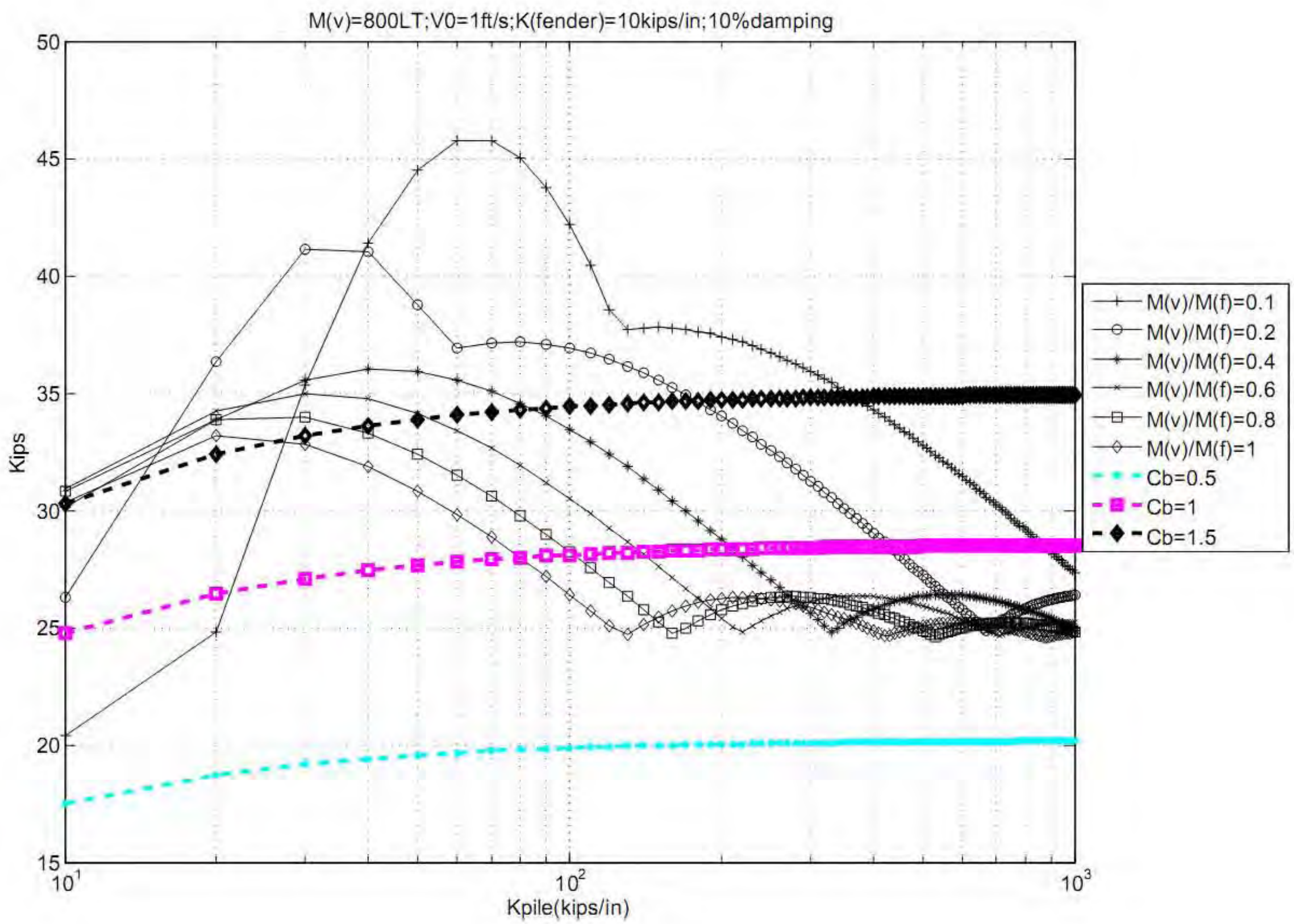
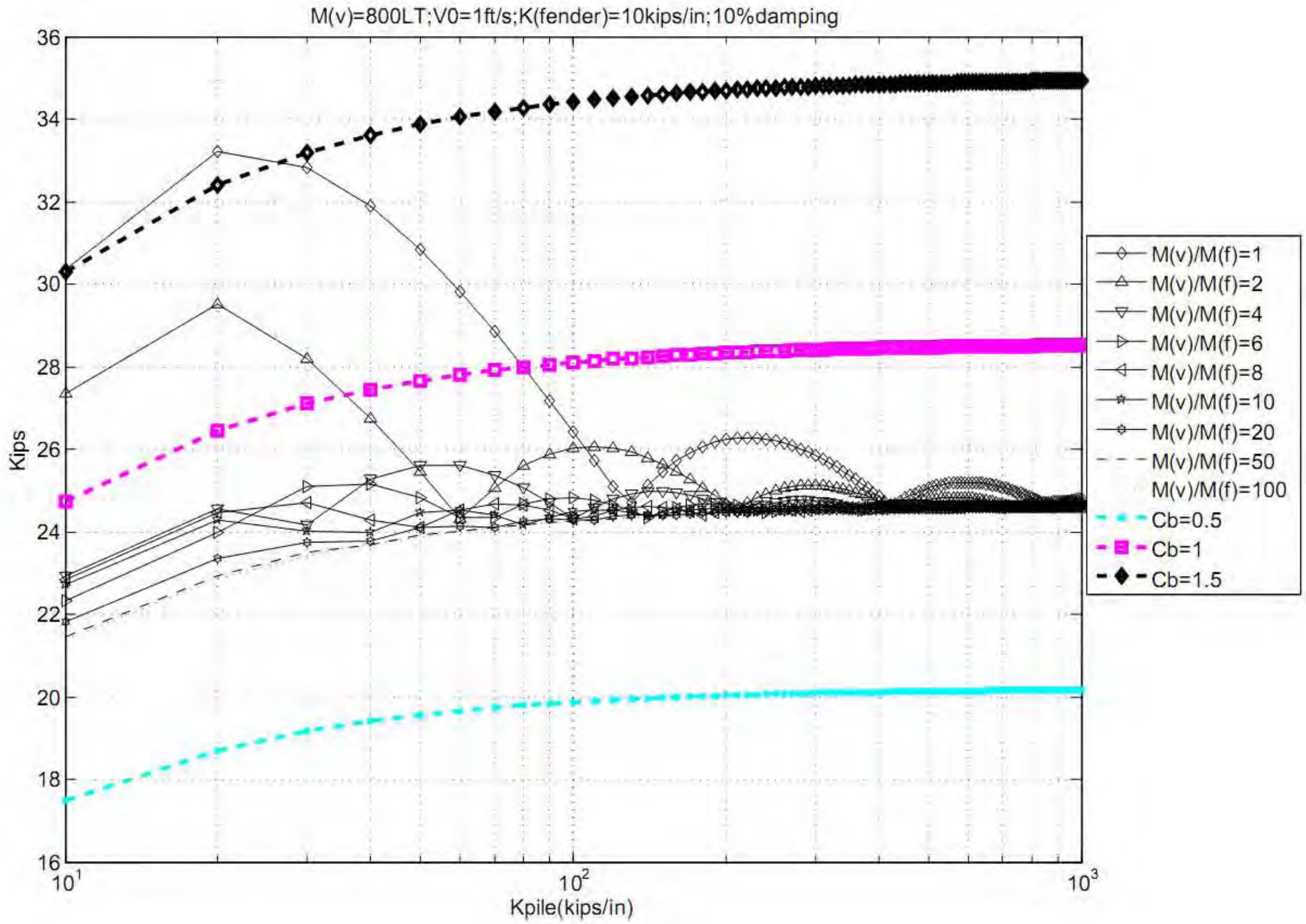
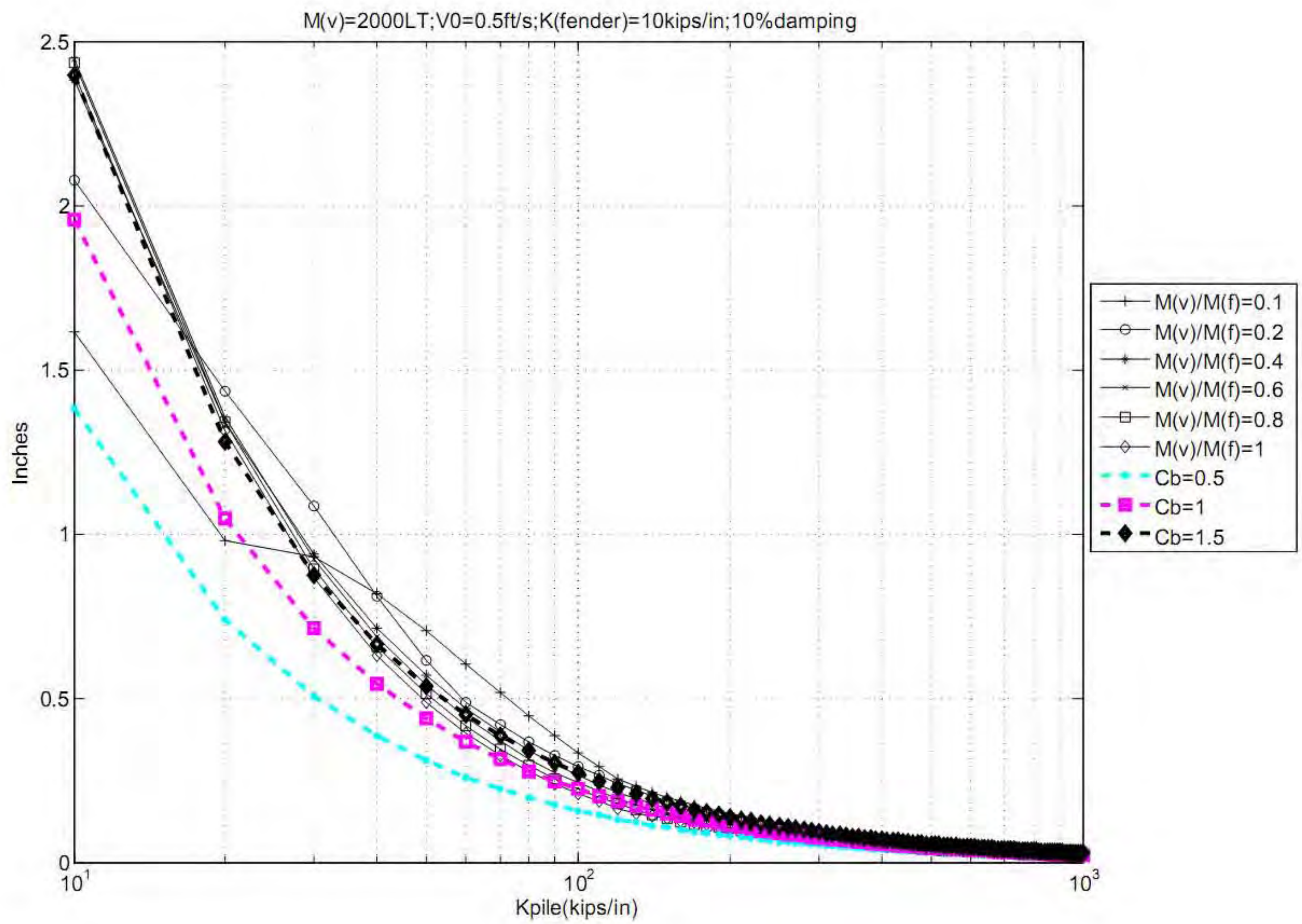

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.71 Reaction Force of the Piling System 1D-18a



M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
36
34
32
30
28
26
24
22
20
18
16
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.72 Reaction Force of the Piling System 1D-18b



M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.73 Displacement of the Piling System 1D-19a

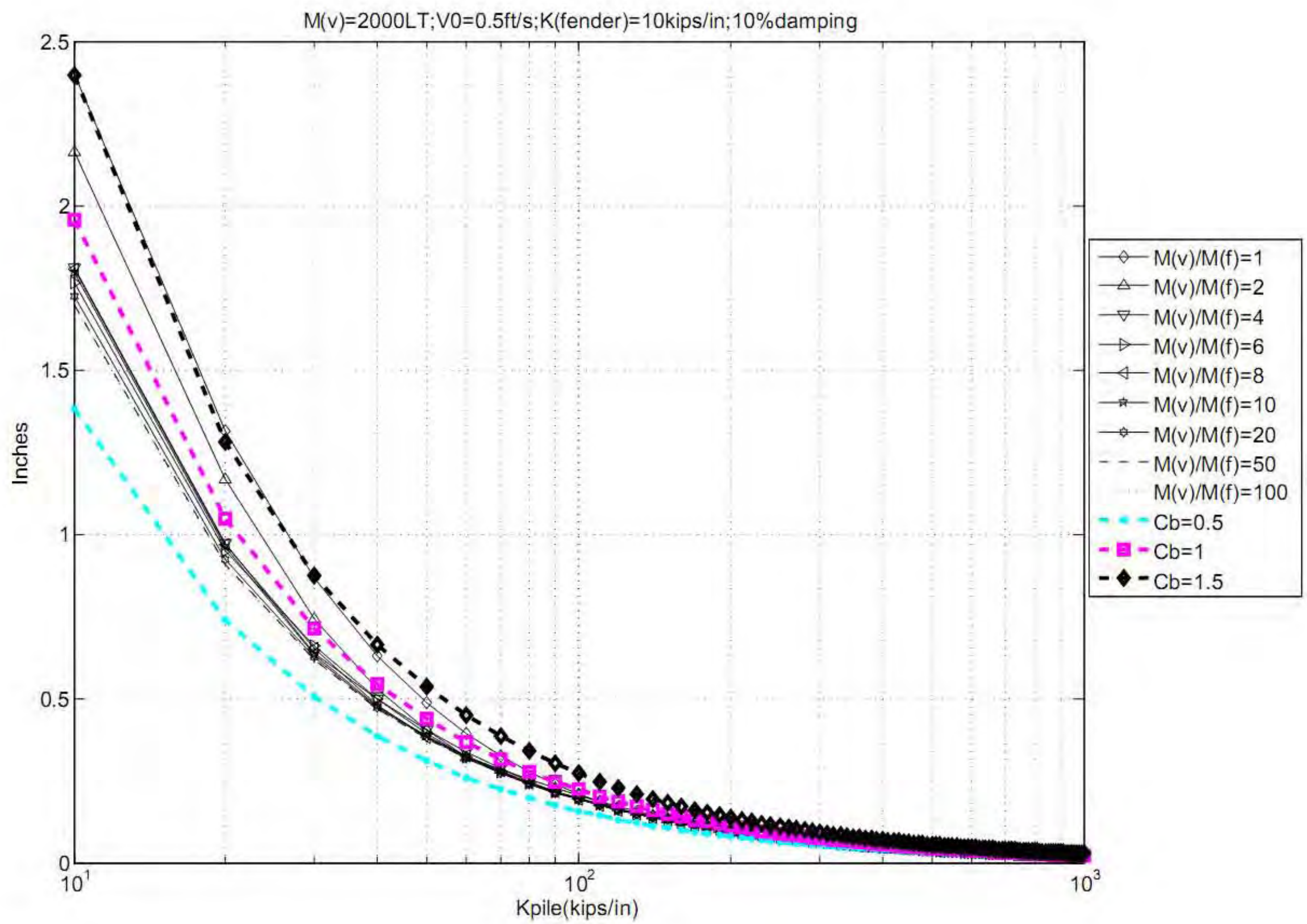

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.74 Displacement of the Piling System 1D-19b

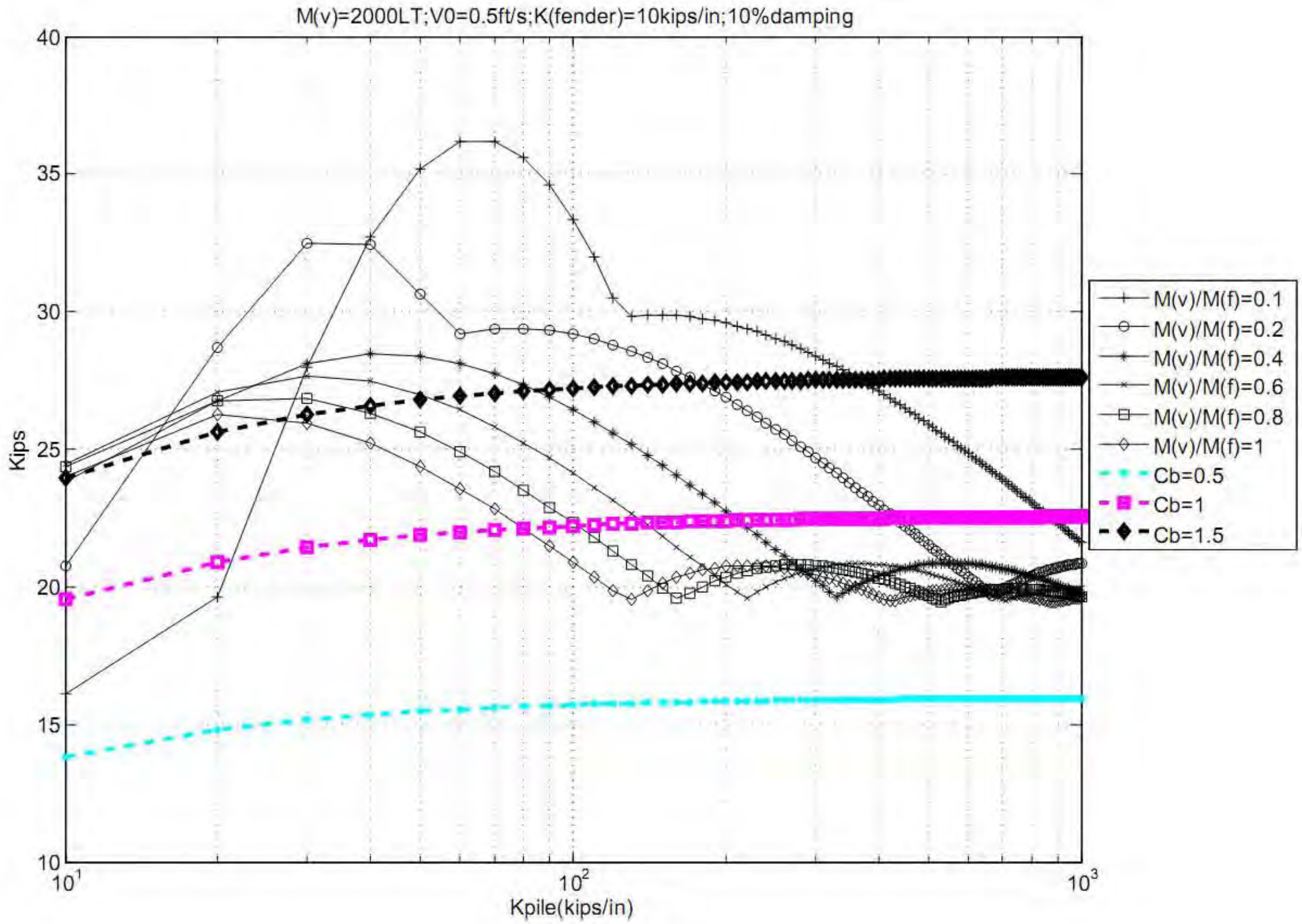
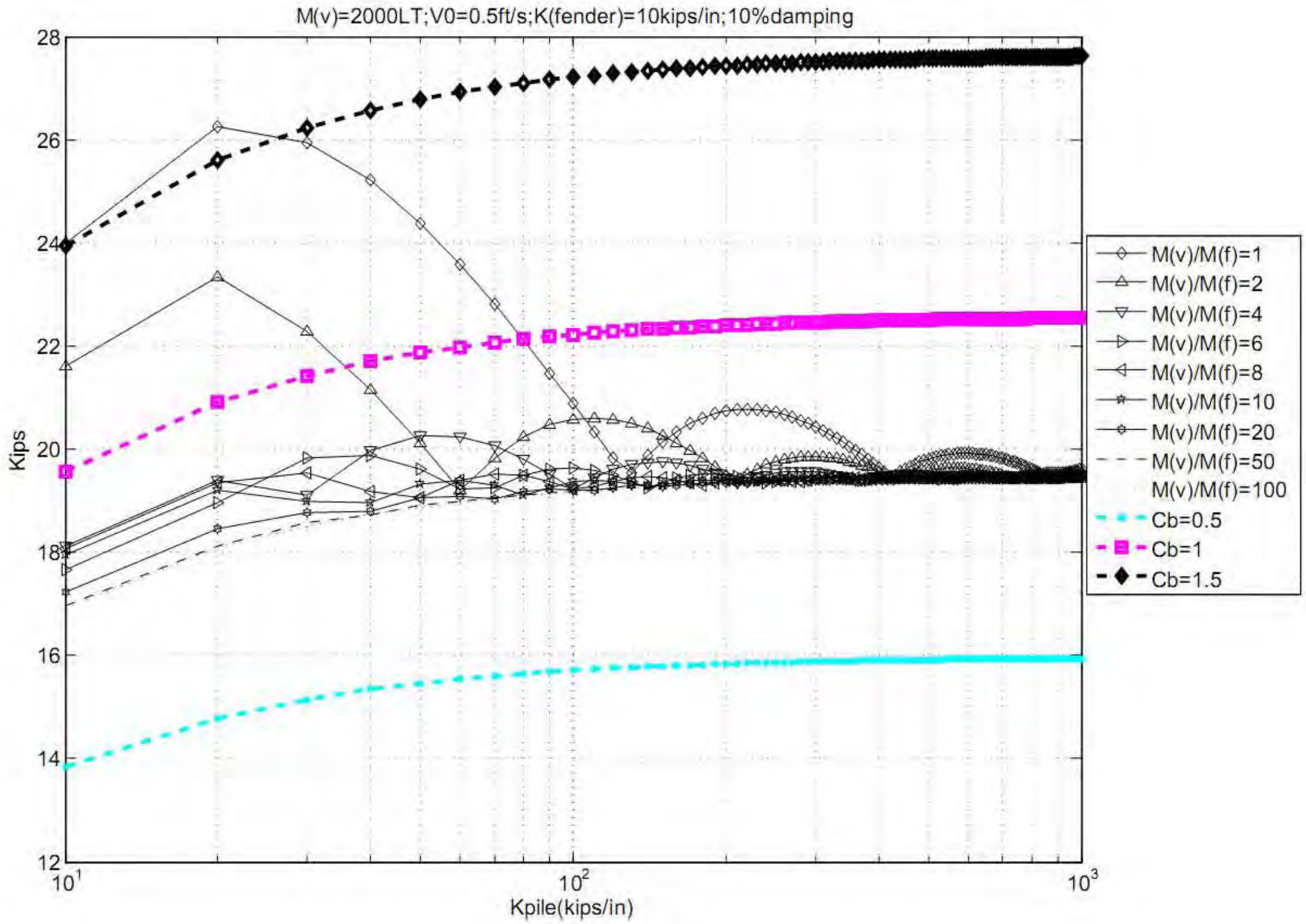
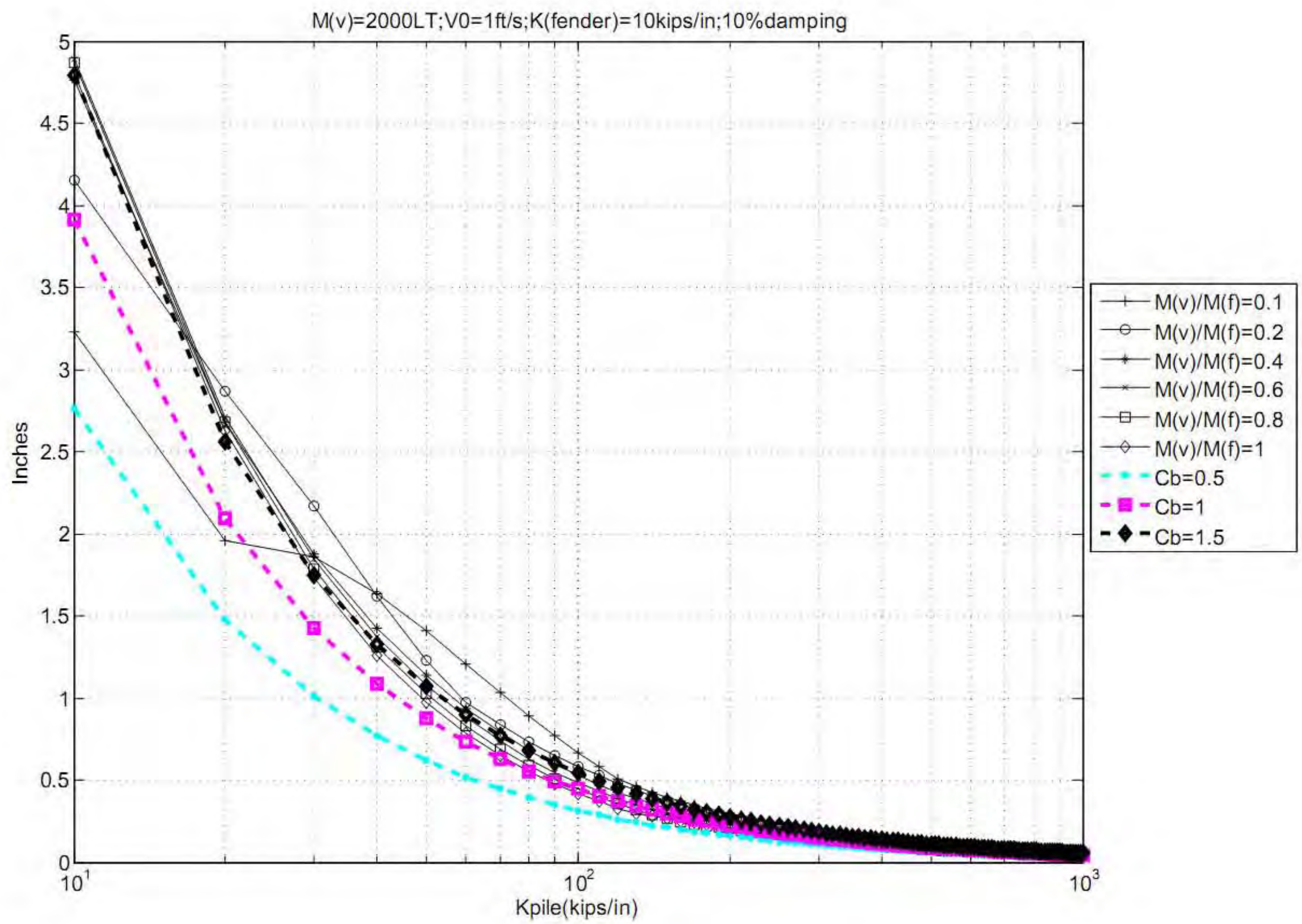

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
40
35
30
25
20
15
10
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.75 Reaction Force of the Piling System 1D-19a



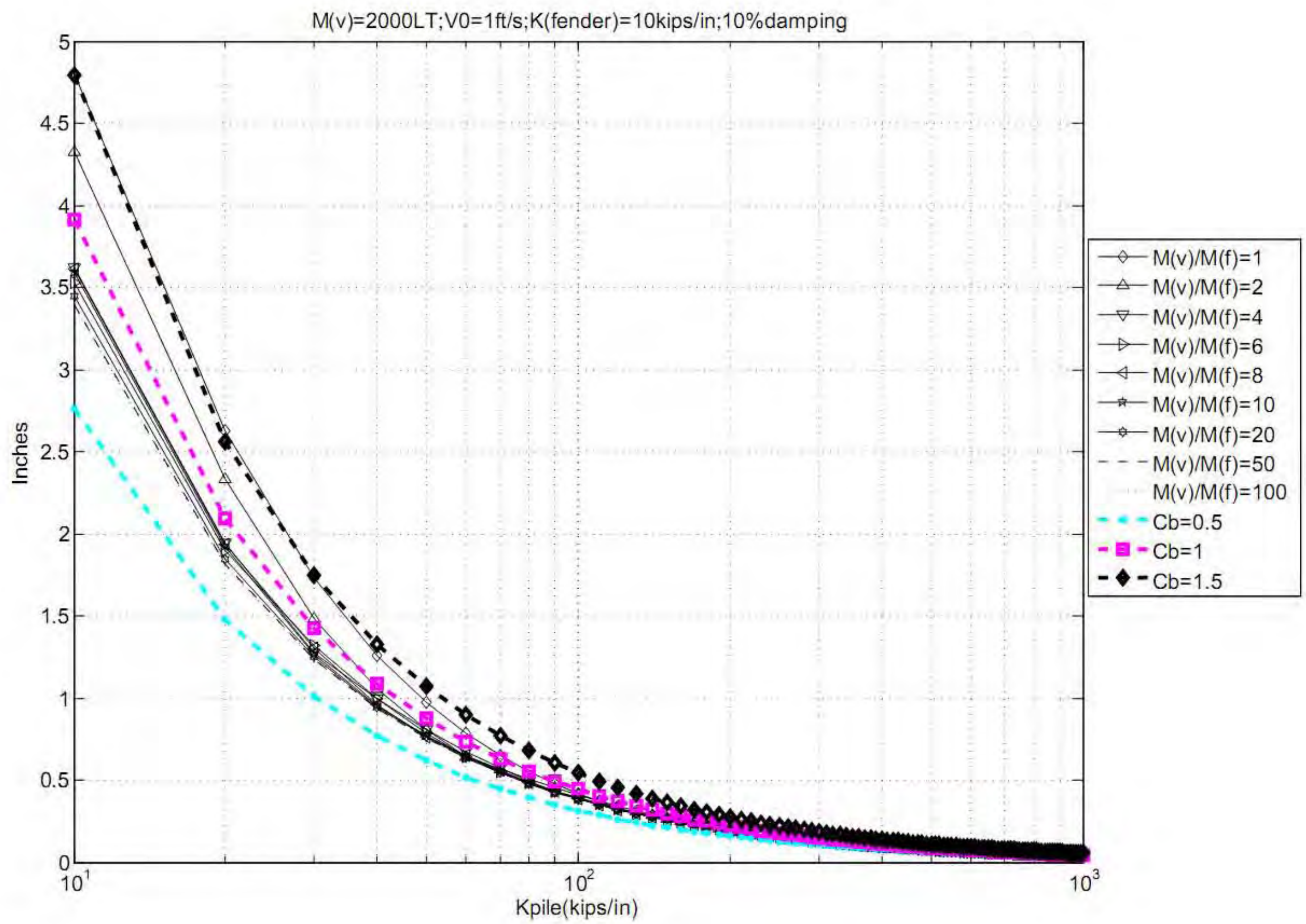
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
28
26
24
22
20
18
16
14
12
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.76 Reaction Force of the Piling System 1D-19b



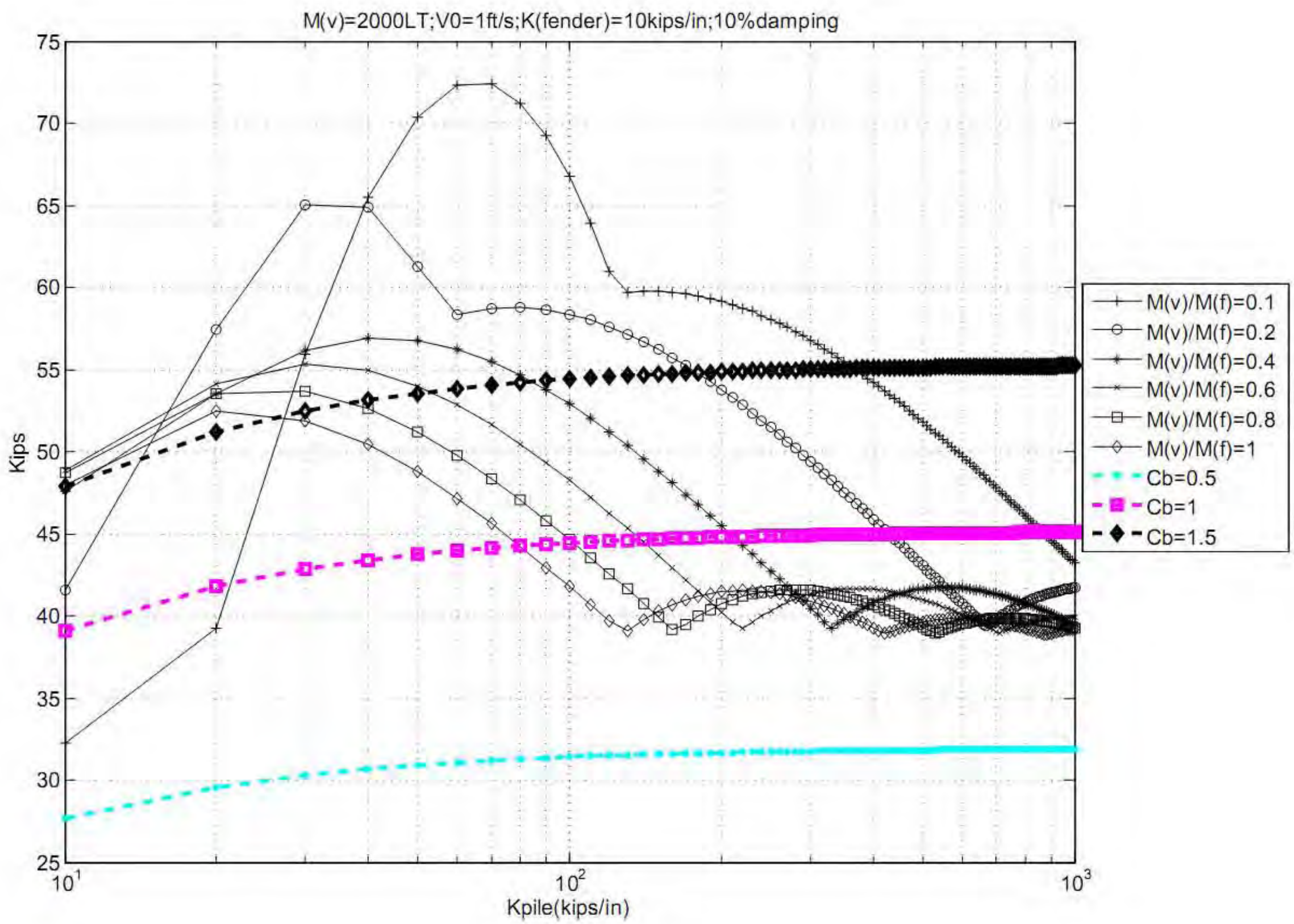
M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.77 Displacement of the Piling System 1D-20a



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.78 Displacement of the Piling System 1D-20b



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
75
70
65
60
55
50
45
40
35
30
25
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.79 Reaction Force of the Piling System 1D-20a

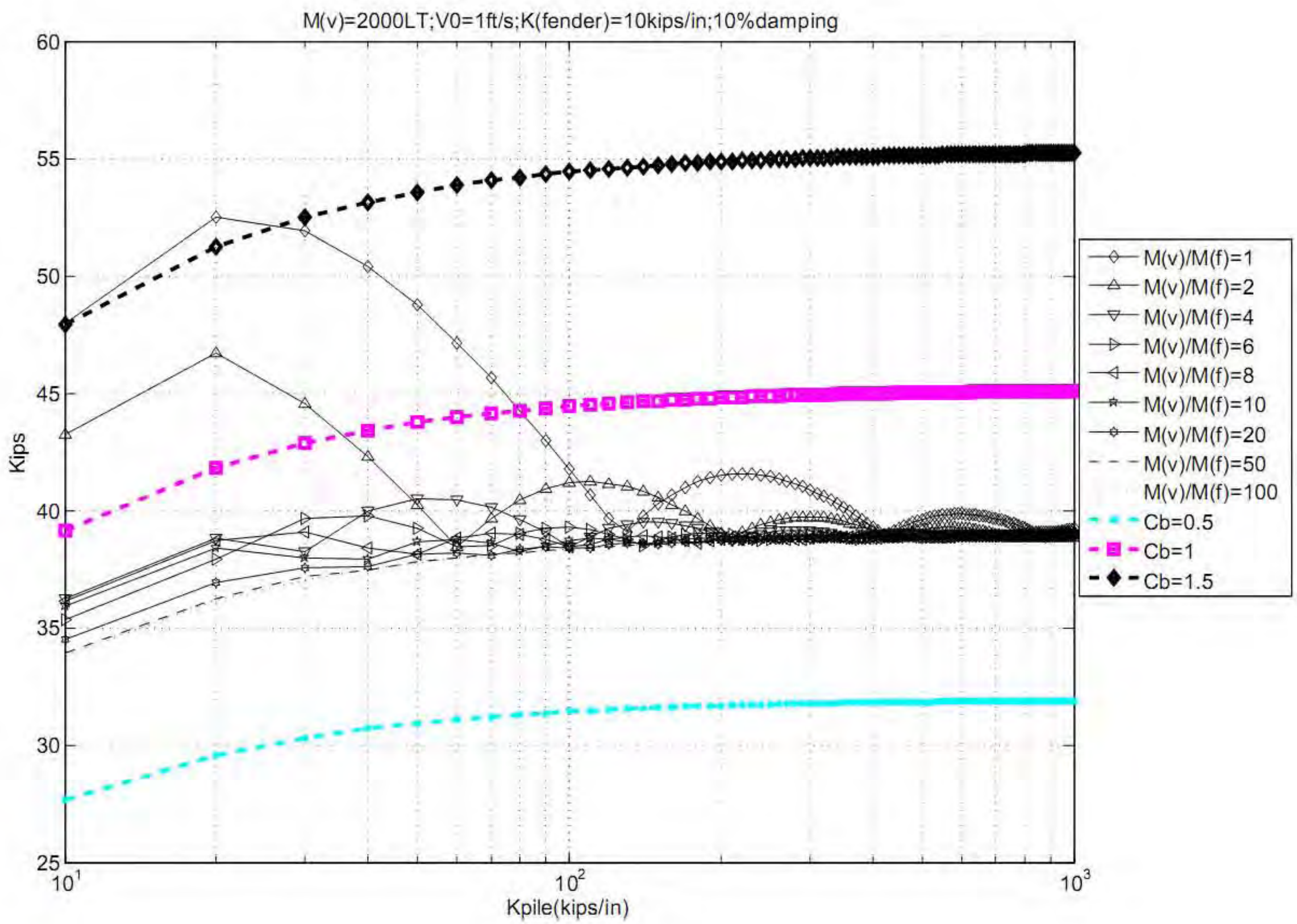
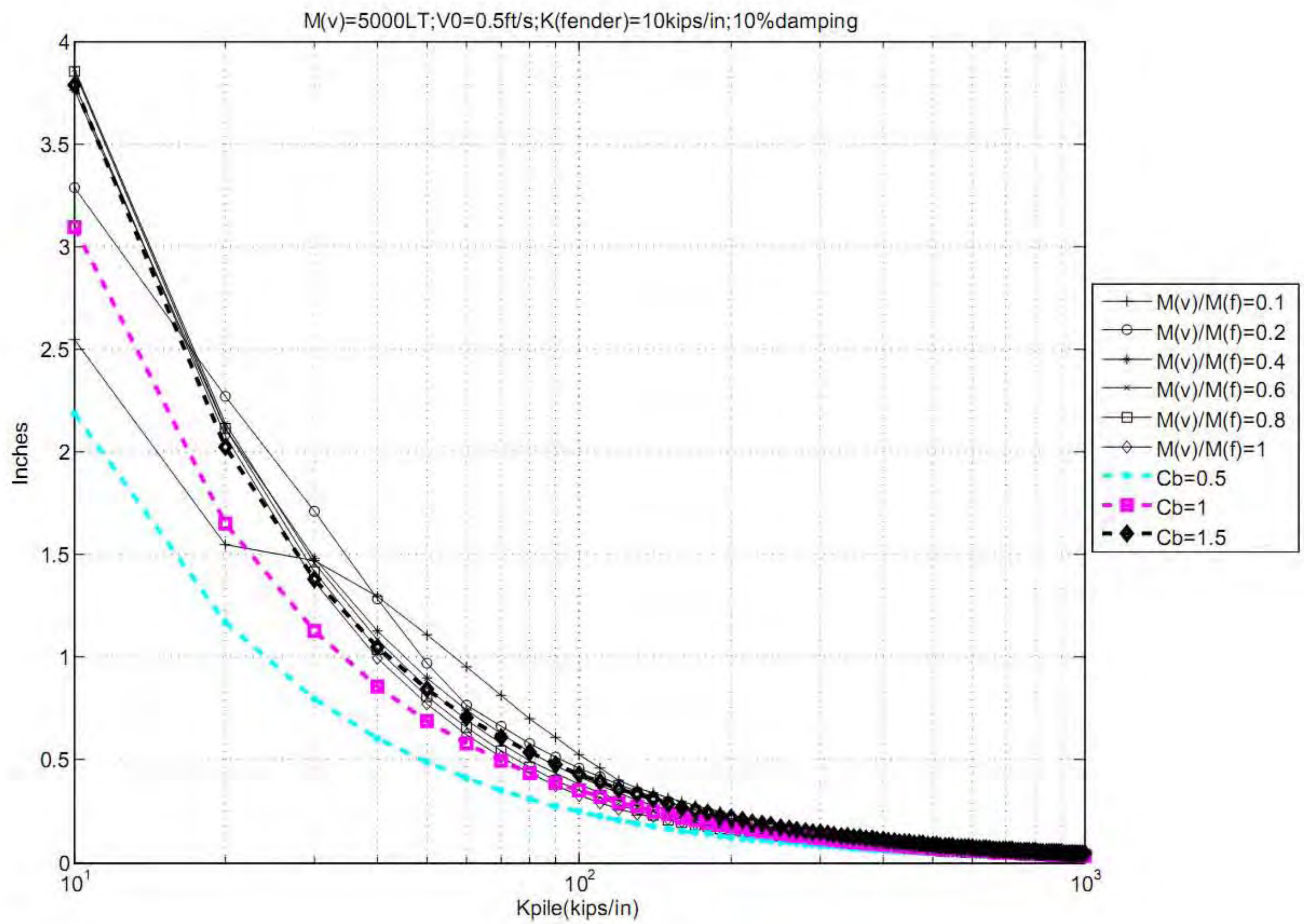
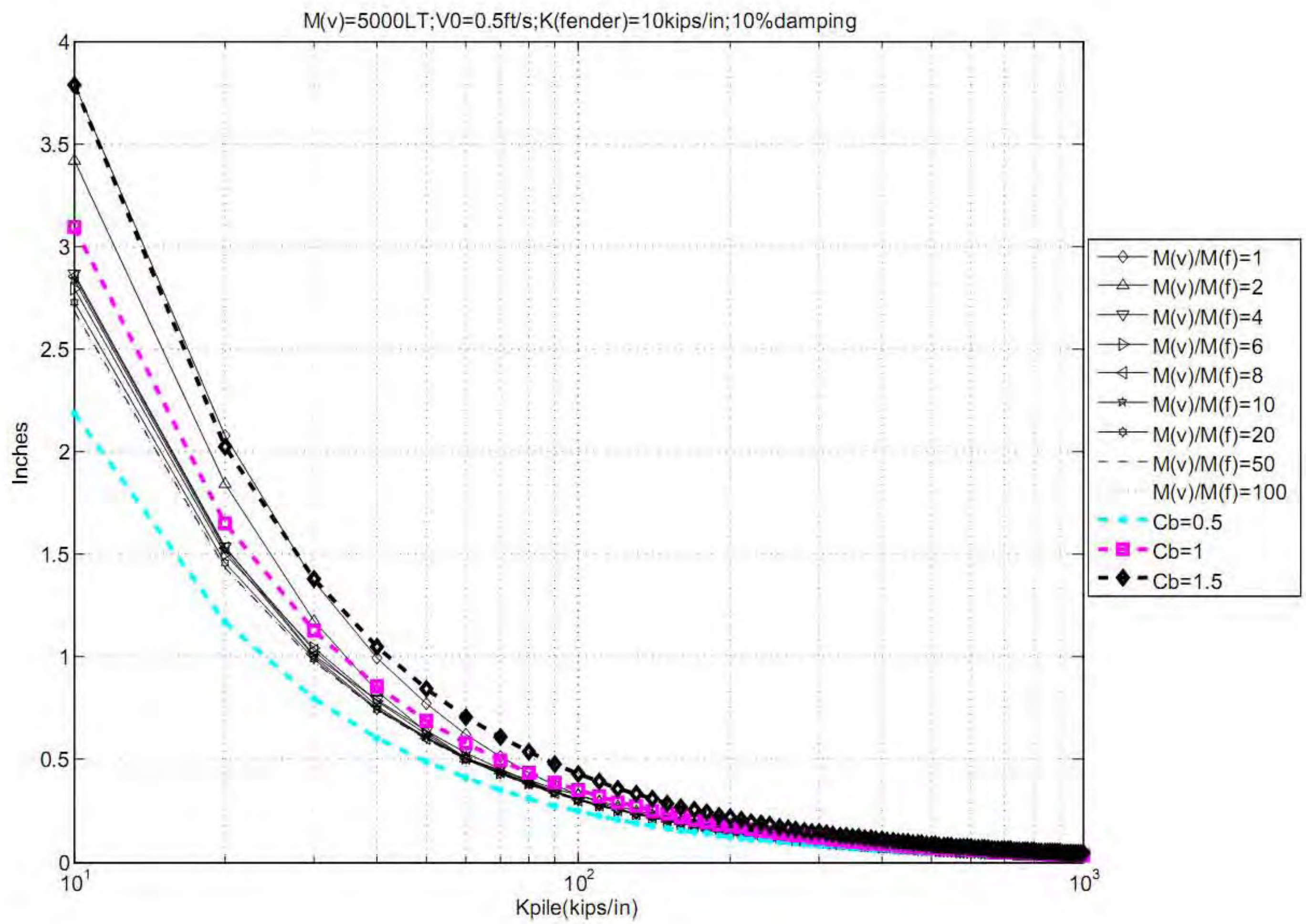

M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.80 Reaction Force of the Piling System 1D-20b



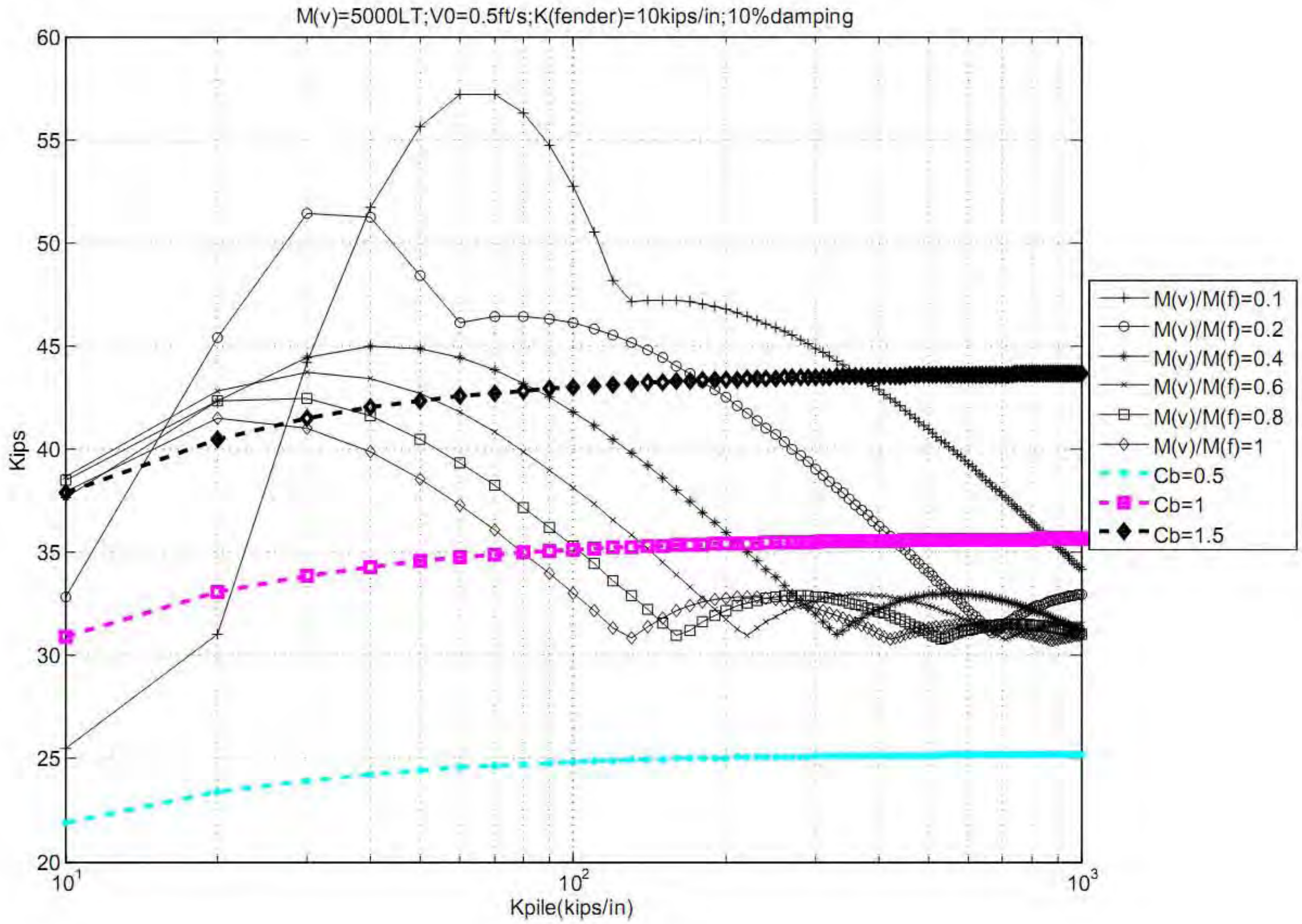
M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
0
0.5
1
1.5
2
2.5
3
3.5
4
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.81 Displacement of the Piling System 1D-21a



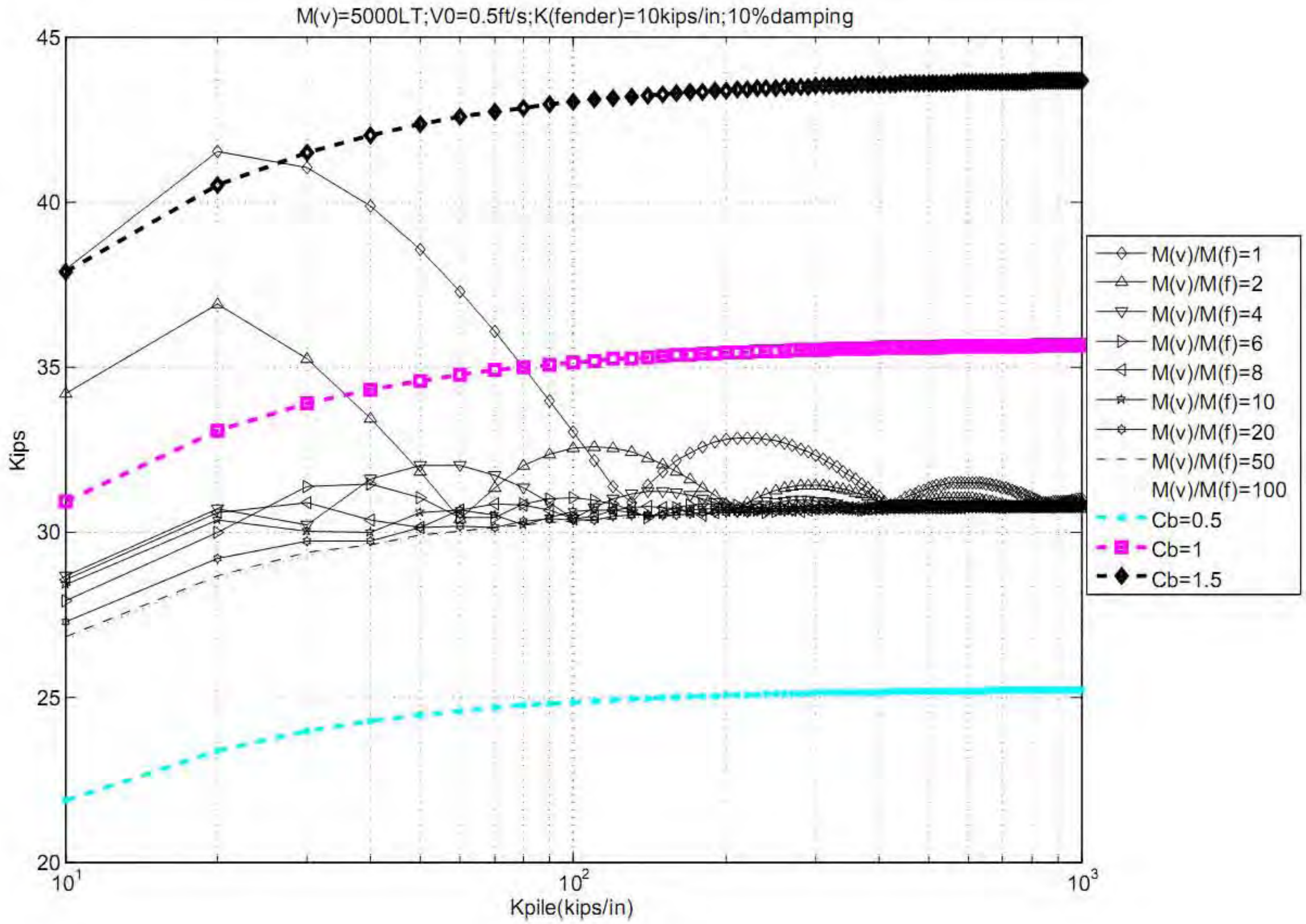
M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
0
0.5
1
1.5
2
2.5
3
3.5
4
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.82 Displacement of the Piling System 1D-21b



M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.83 Reaction Force of the Piling System 1D-21a



M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.84 Reaction Force of the Piling System 1D-21b

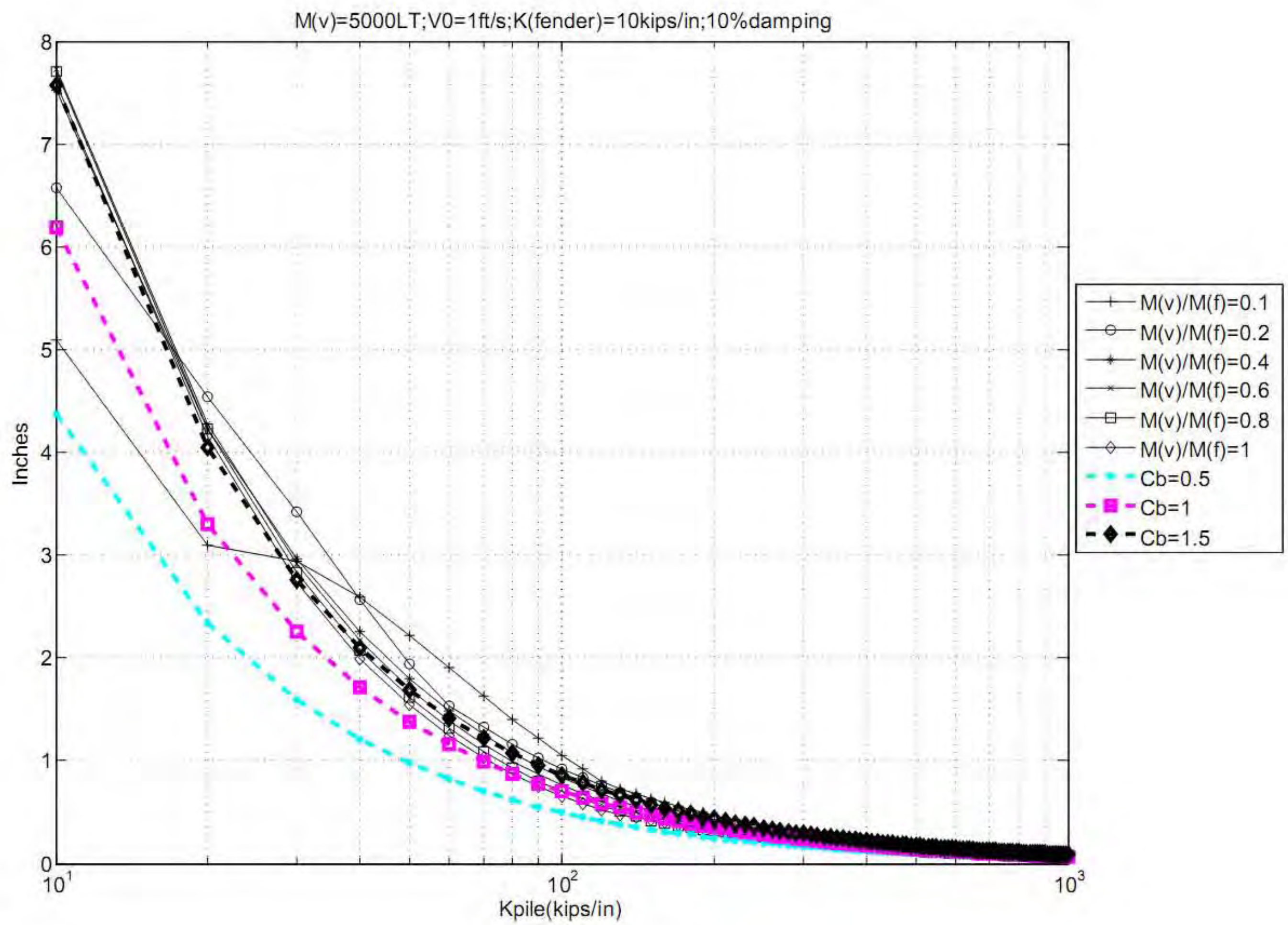

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.85 Displacement of the Piling System 1D-22a

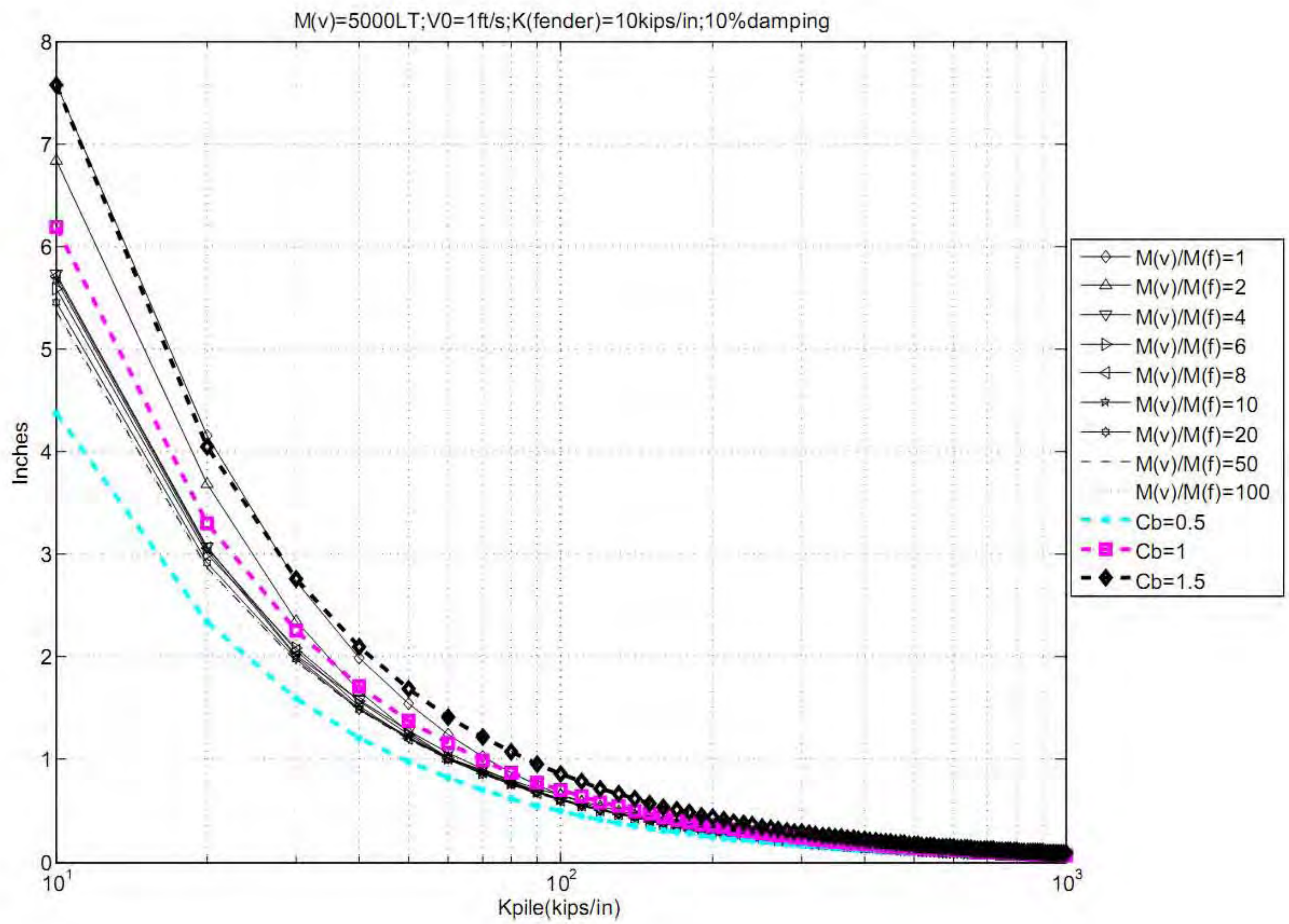

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.86 Displacement of the Piling System 1D-22b

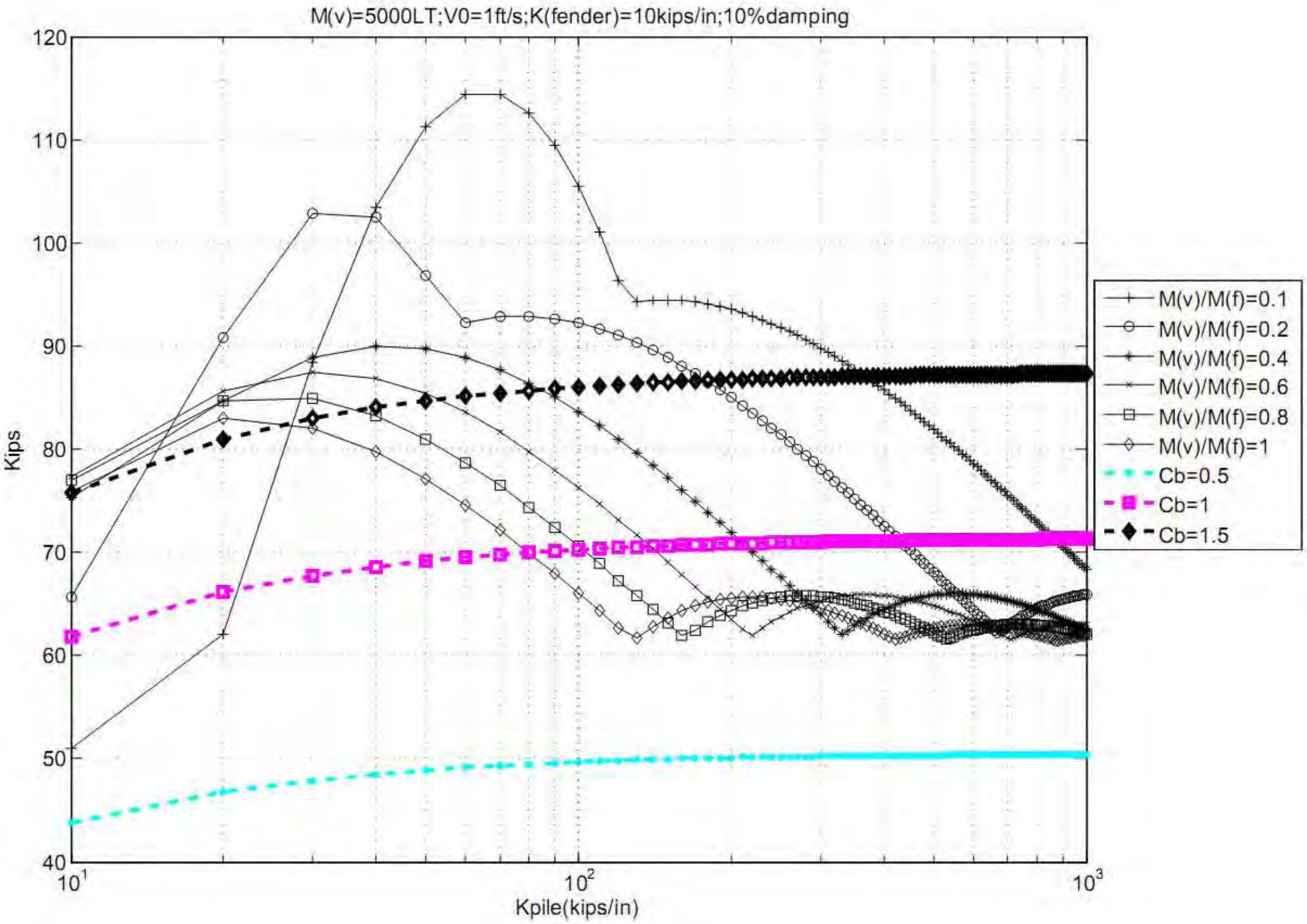
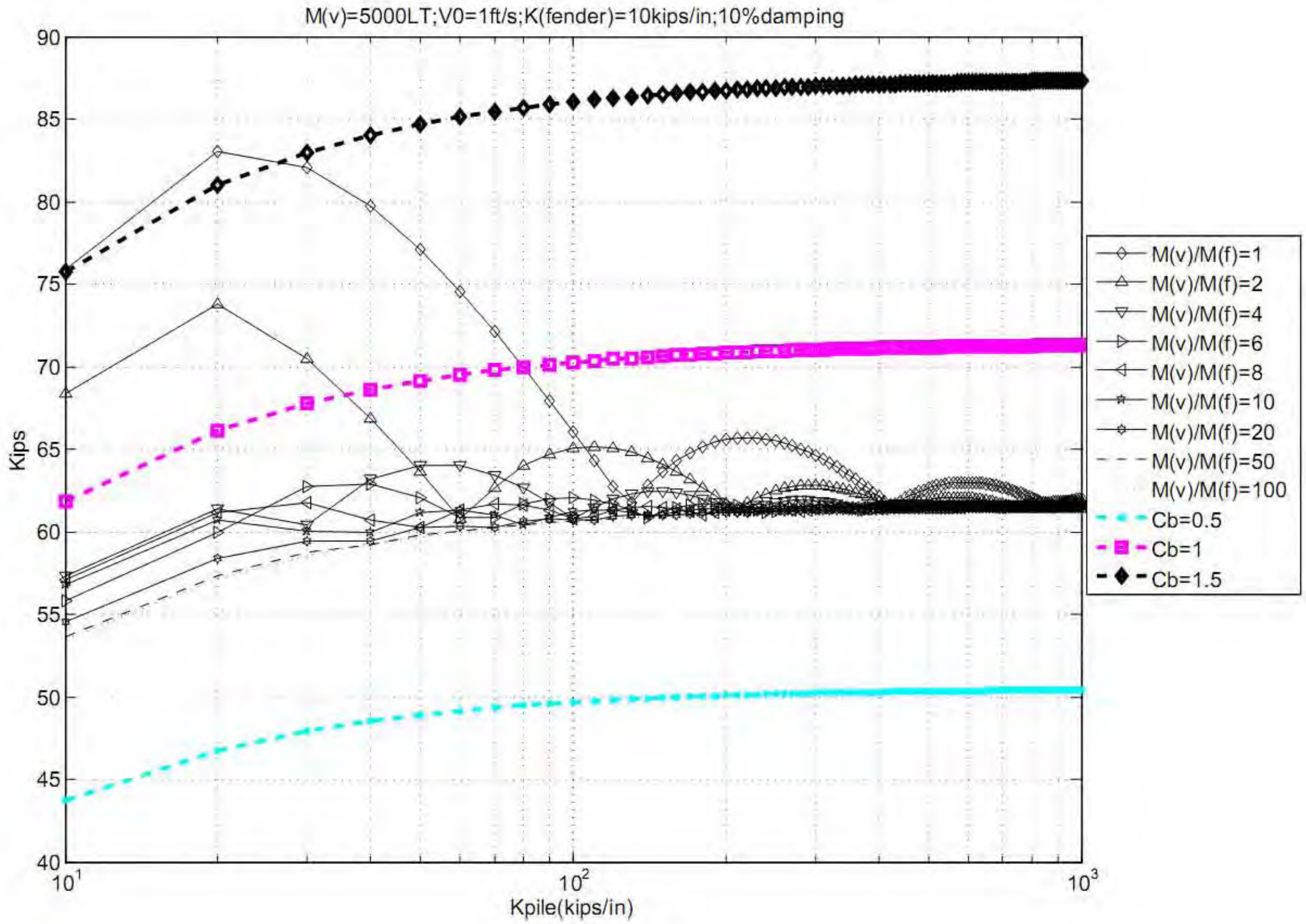

M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
120
110
100
90
80
70
60
50
40
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.87 Reaction Force of the Piling System 1D-22a



M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.88 Reaction Force of the Piling System 1D-22b

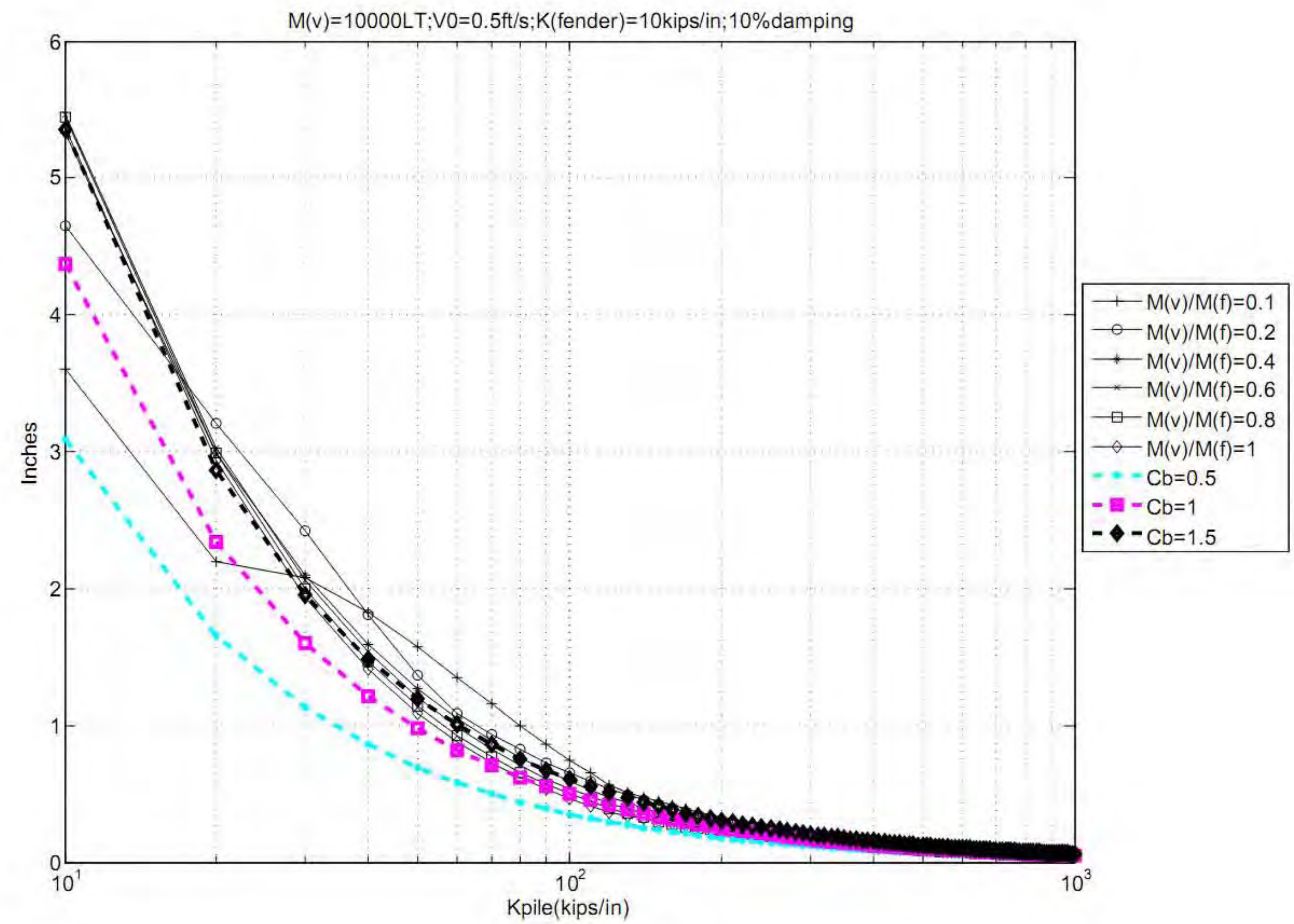
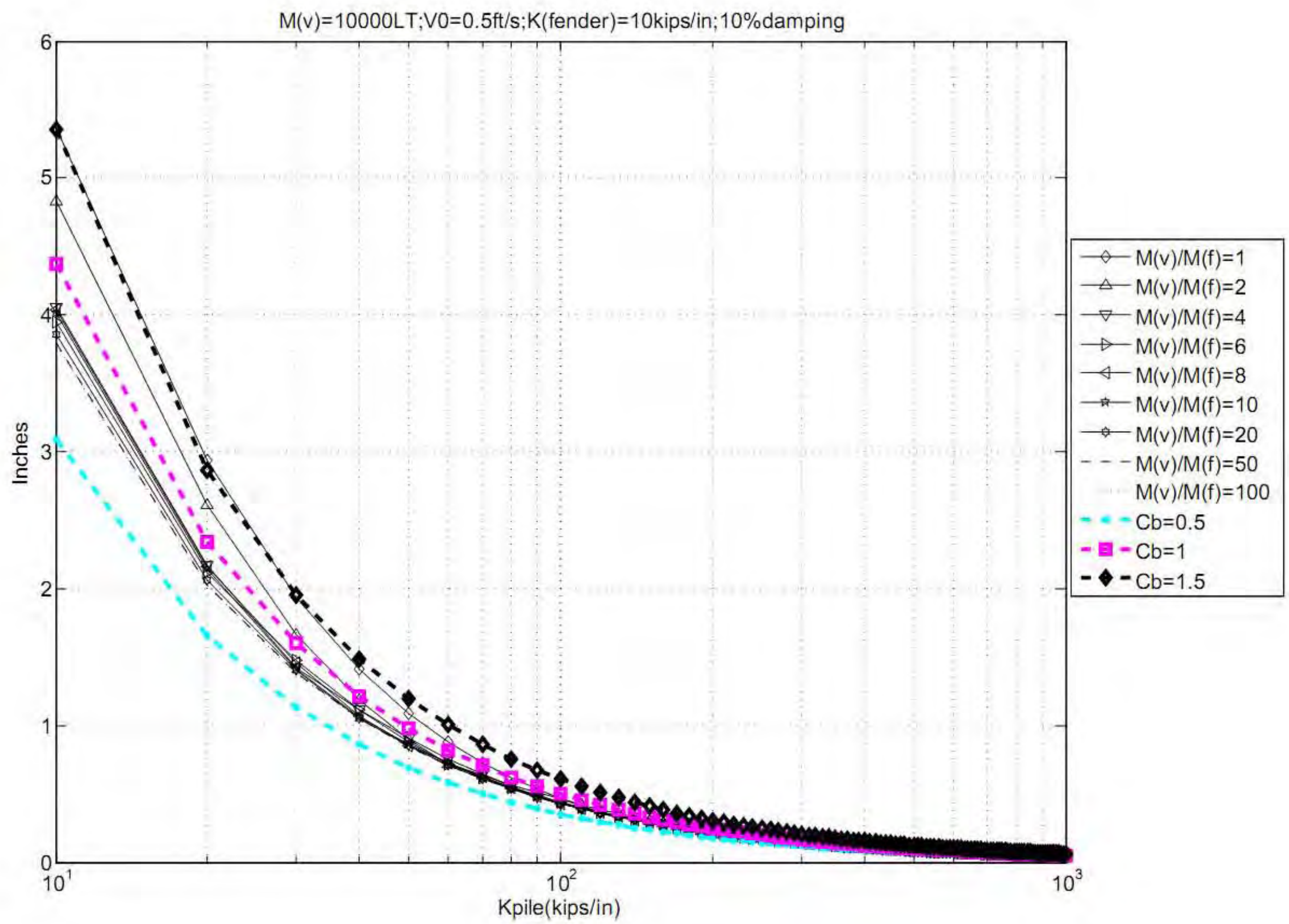

M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.89 Displacement of the Piling System 1D-23a



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
0
1
2
3
4
5
6
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.90 Displacement of the Piling System 1D-23b

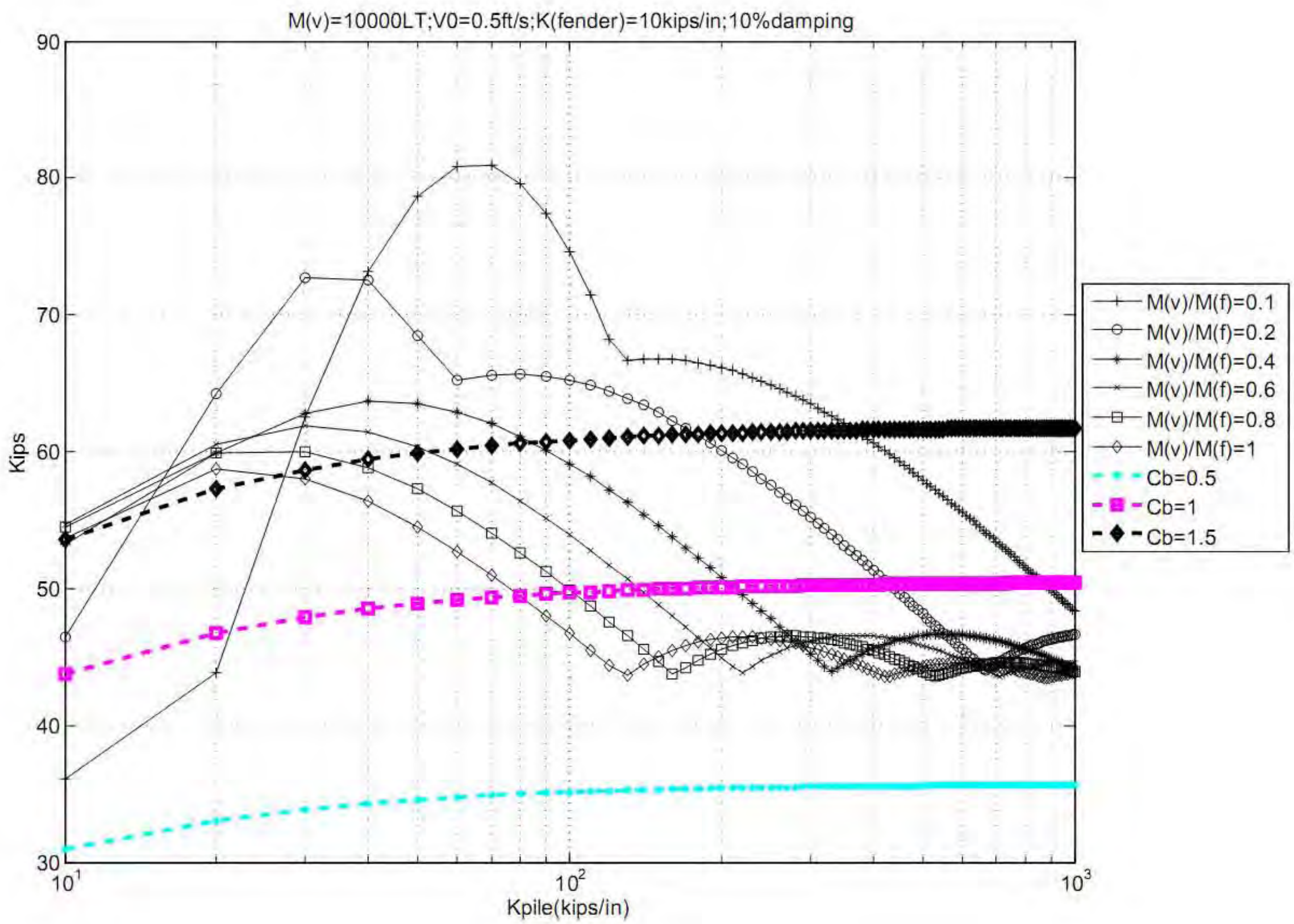

M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.91 Reaction Force of the Piling System 1D-23a

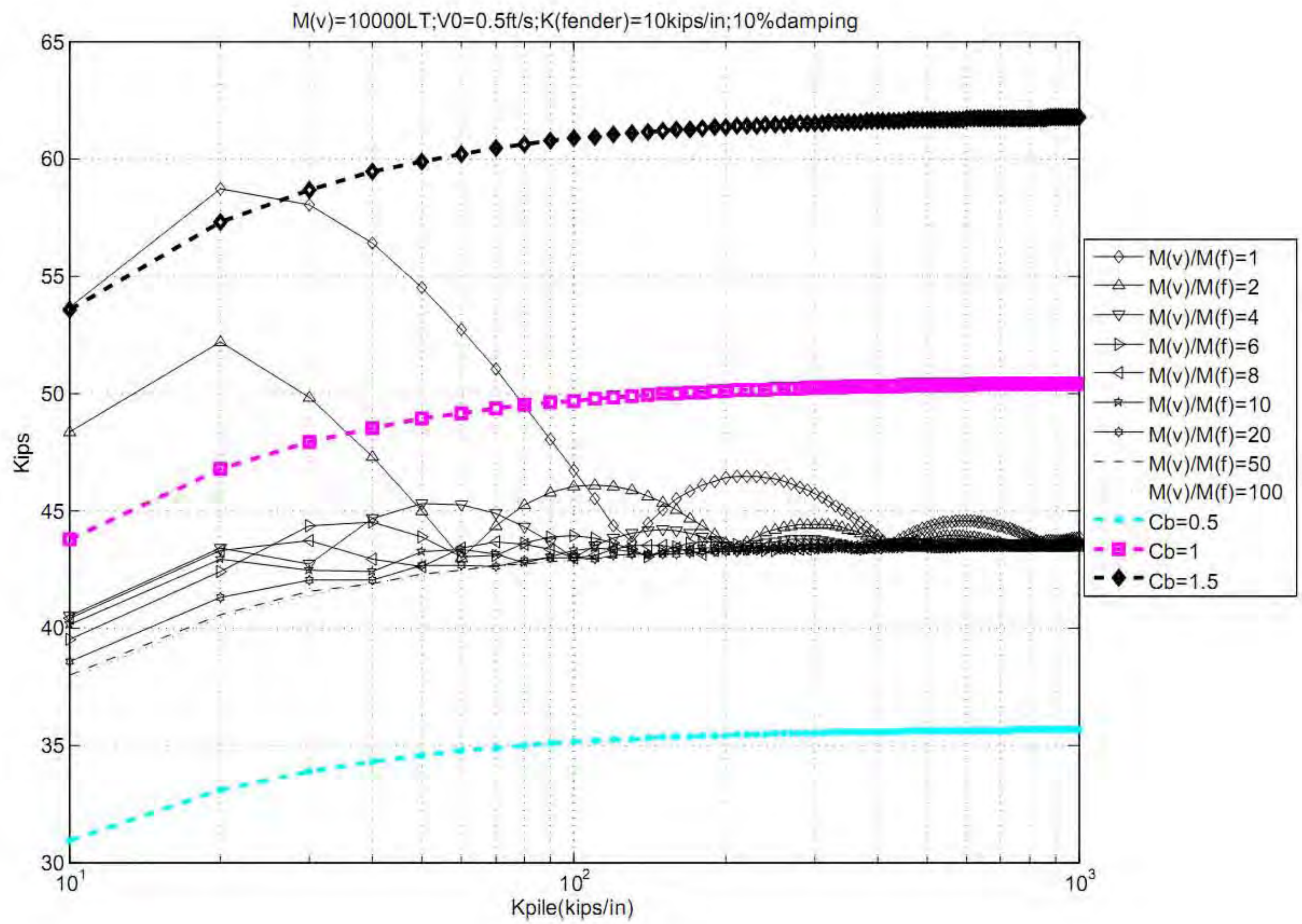

M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;10%damping
Kips
Kpile(kips/in)
65
60
55
50
45
40
35
30
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.92 Reaction Force of the Piling System 1D-23b

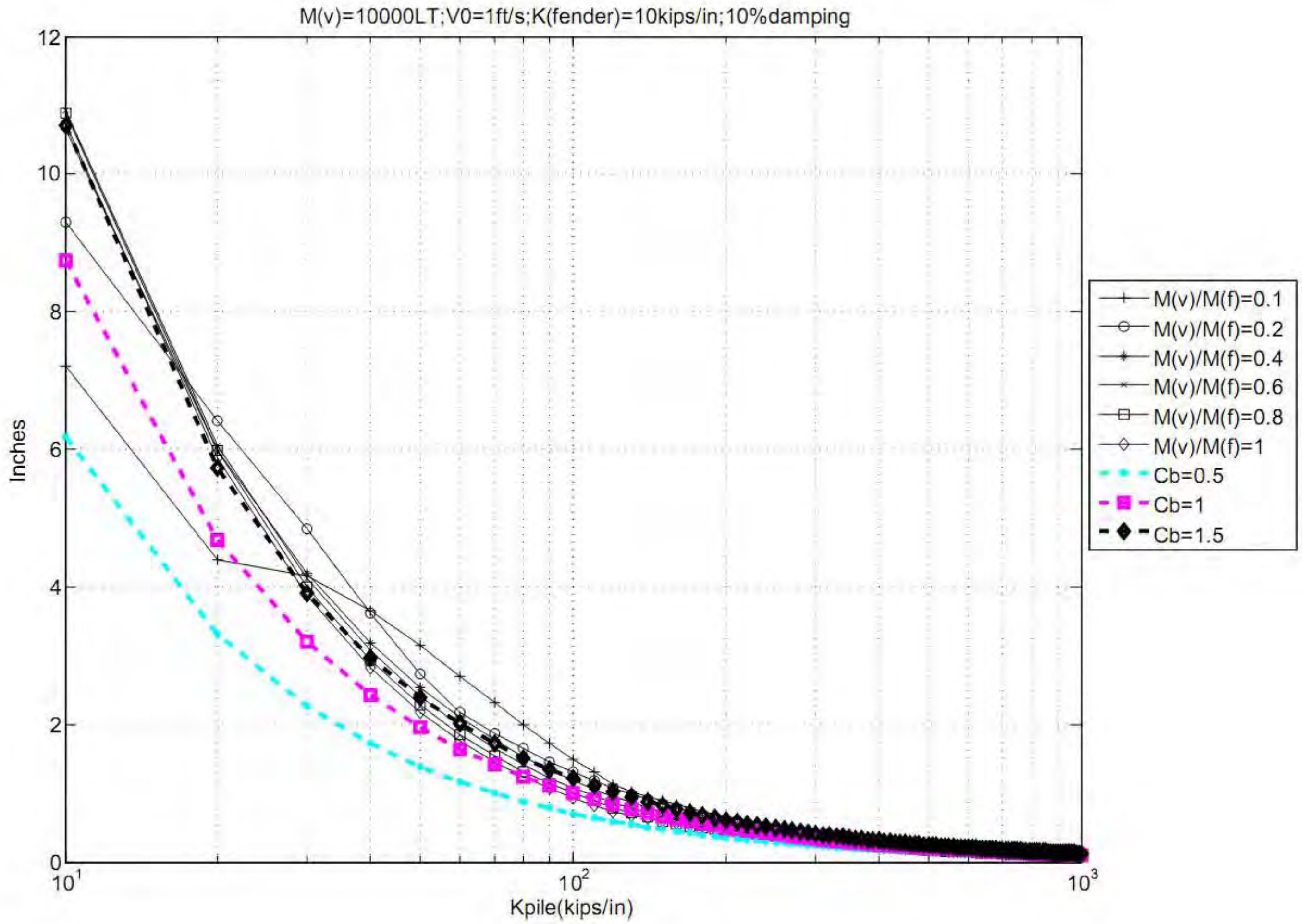
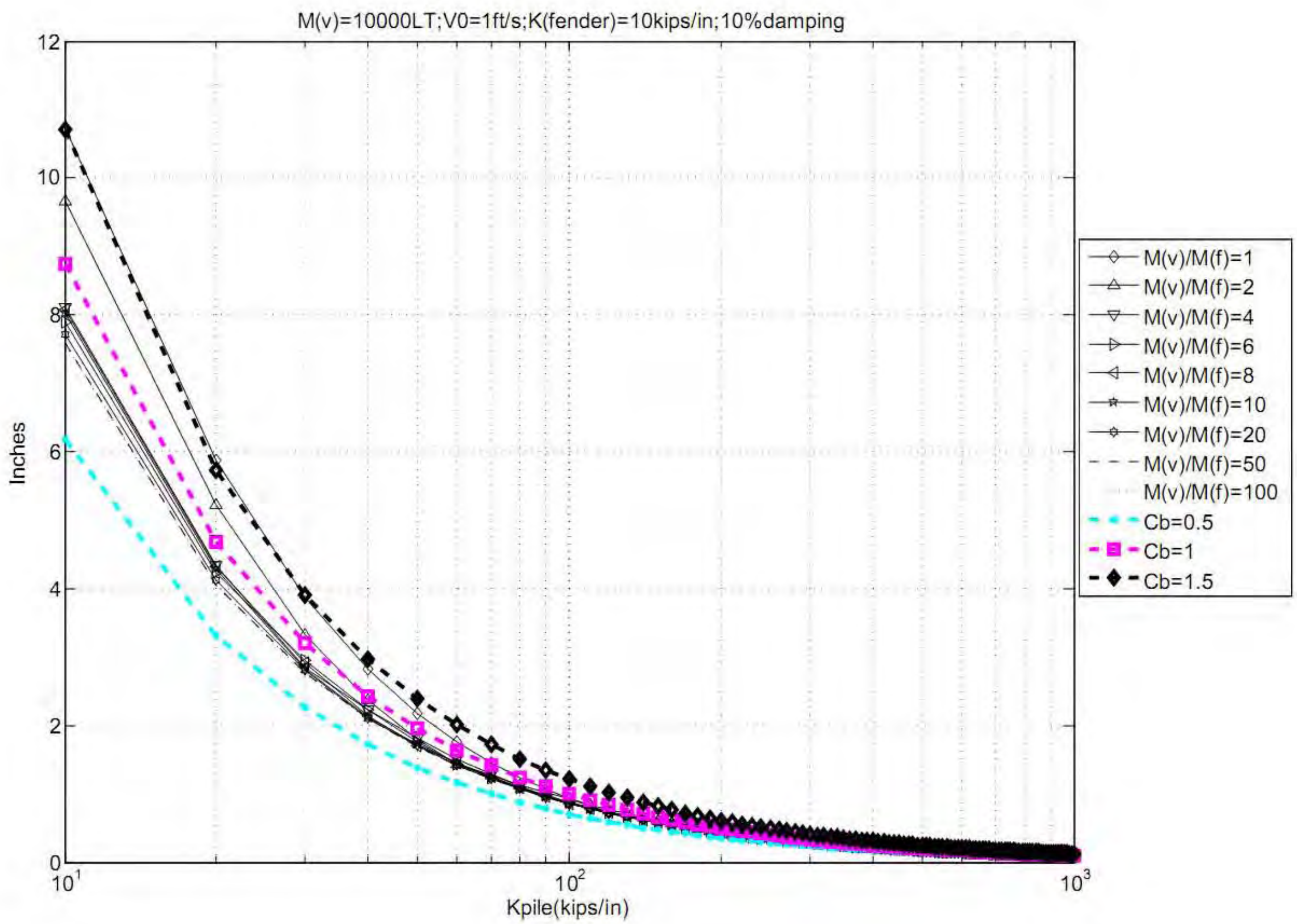

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
12
10
8
6
4
2
0
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.93 Displacement of the Piling System 1D-24a



M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.94 Displacement of the Piling System 1D-24b

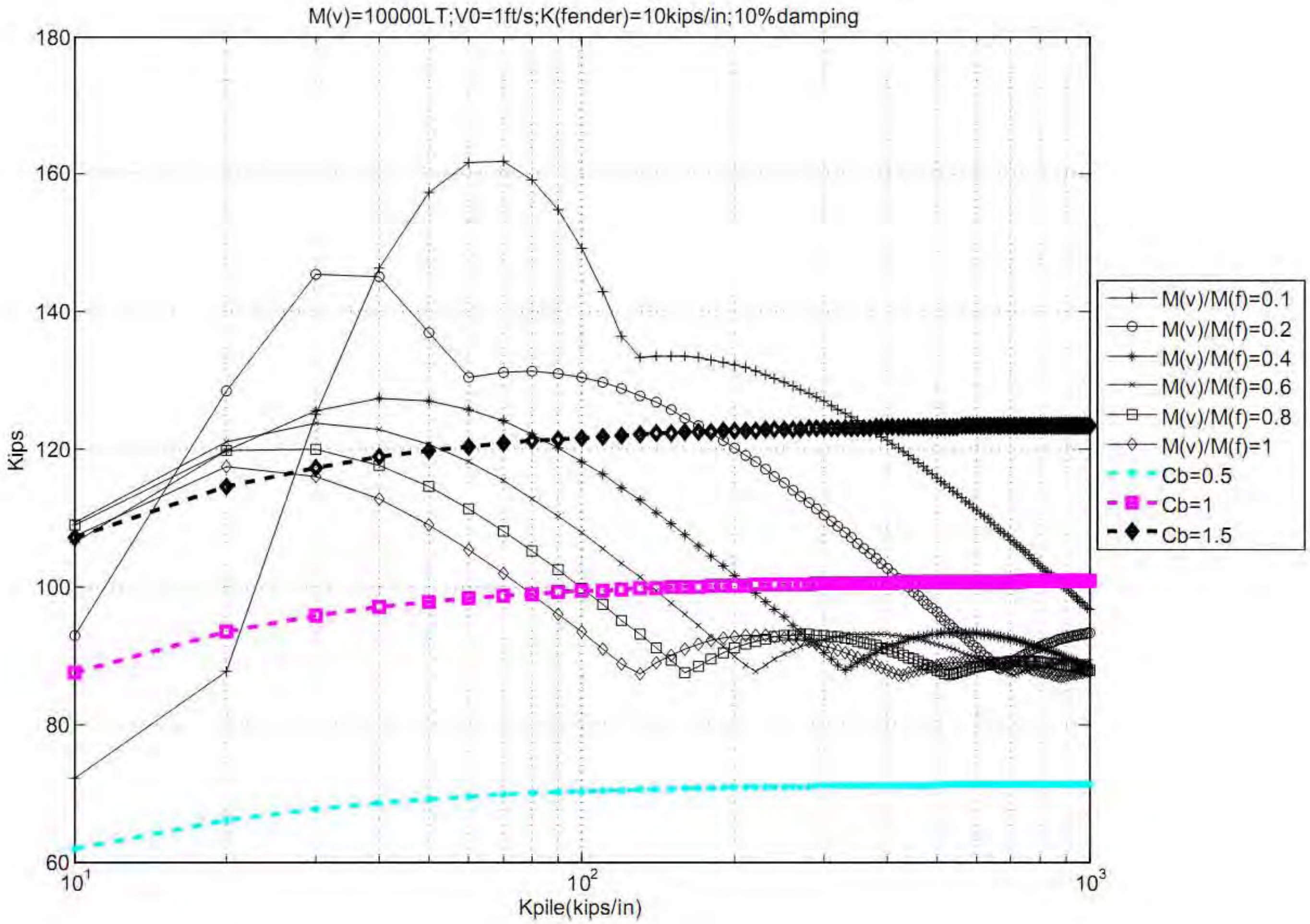

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
180
160
140
120
100
80
60
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.95 Reaction Force of the Piling System 1D-24a

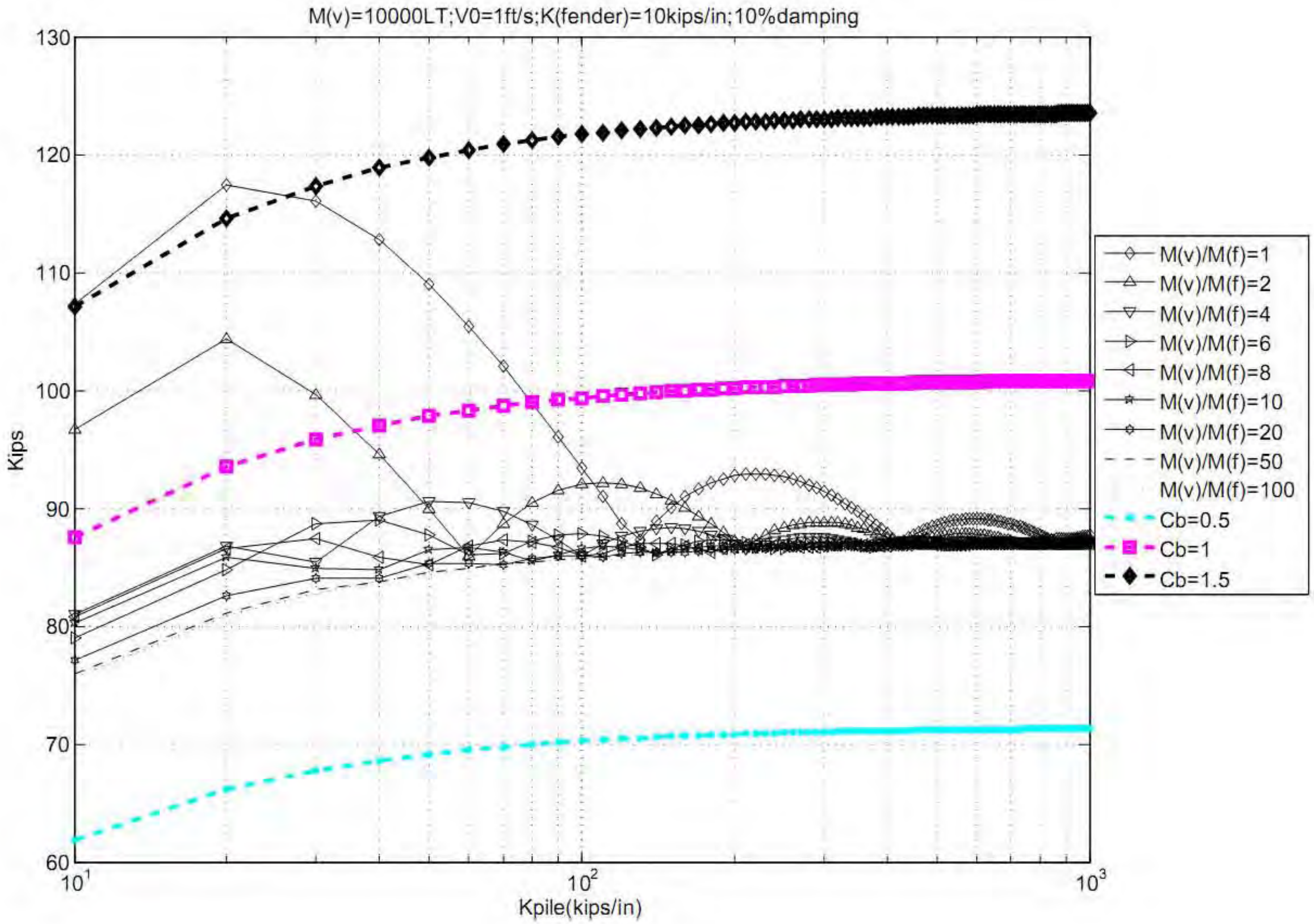
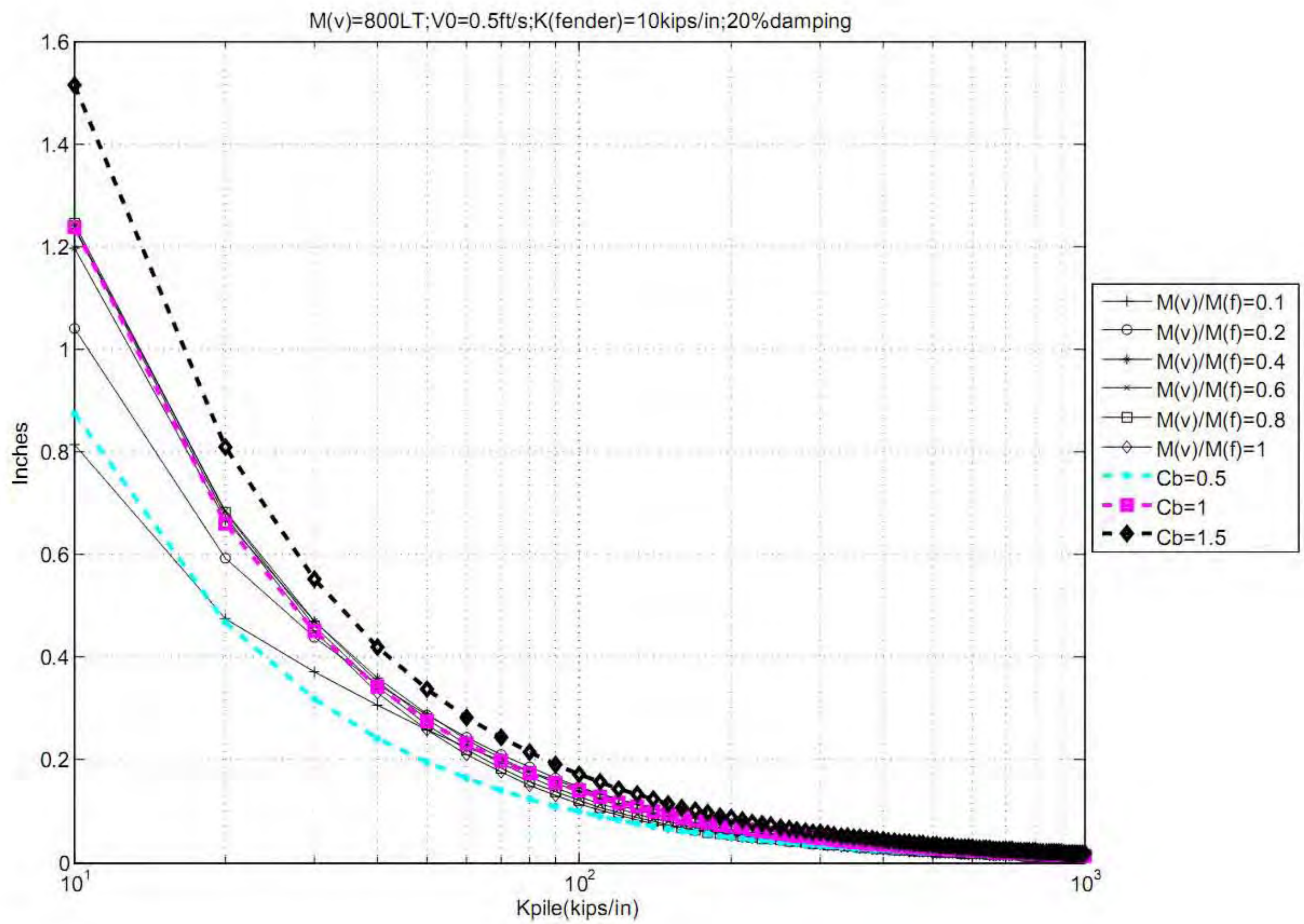
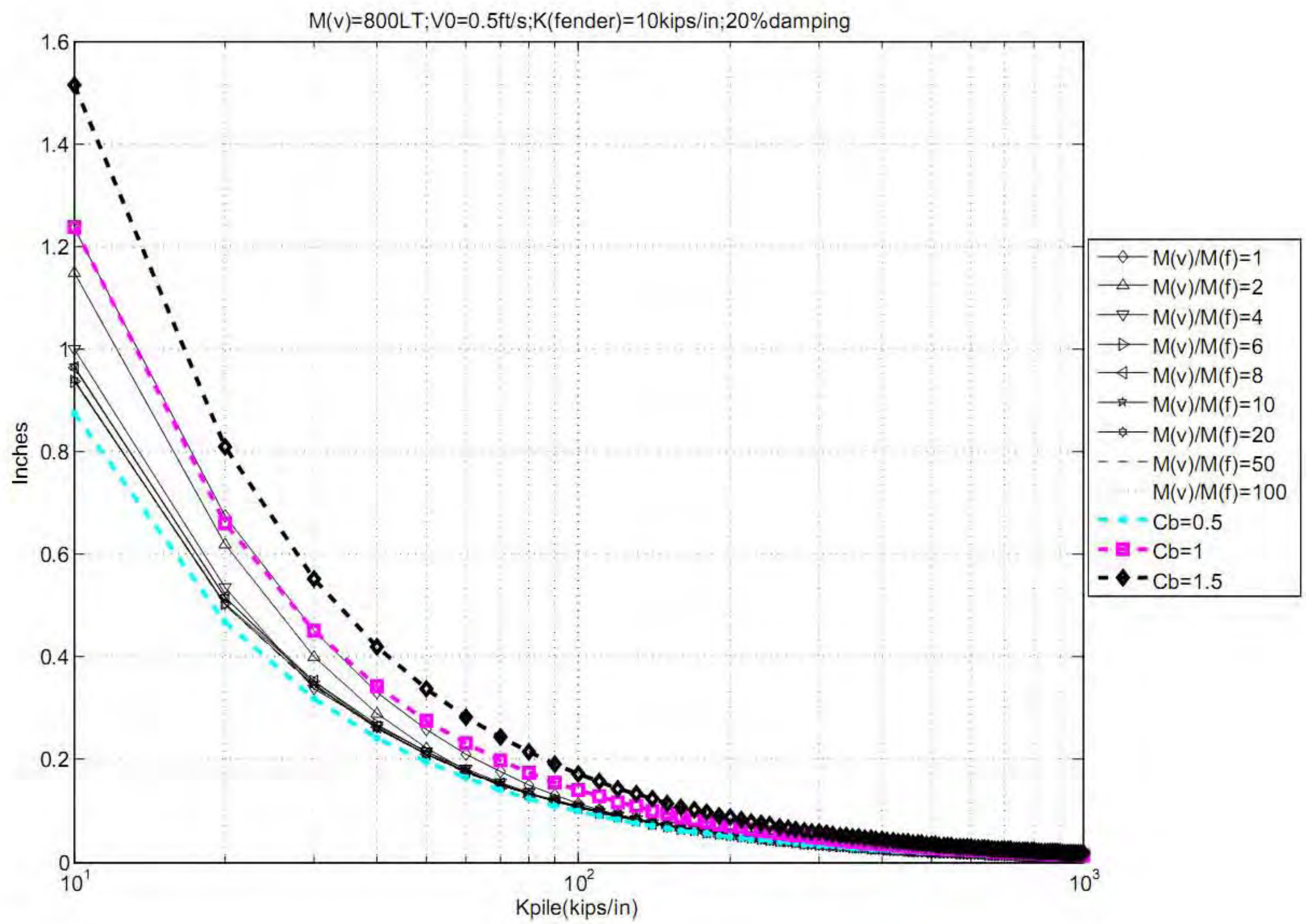

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;10%damping
130
120
110
100
90
80
70
60
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.96 Reaction Force of the Piling System 1D-24b



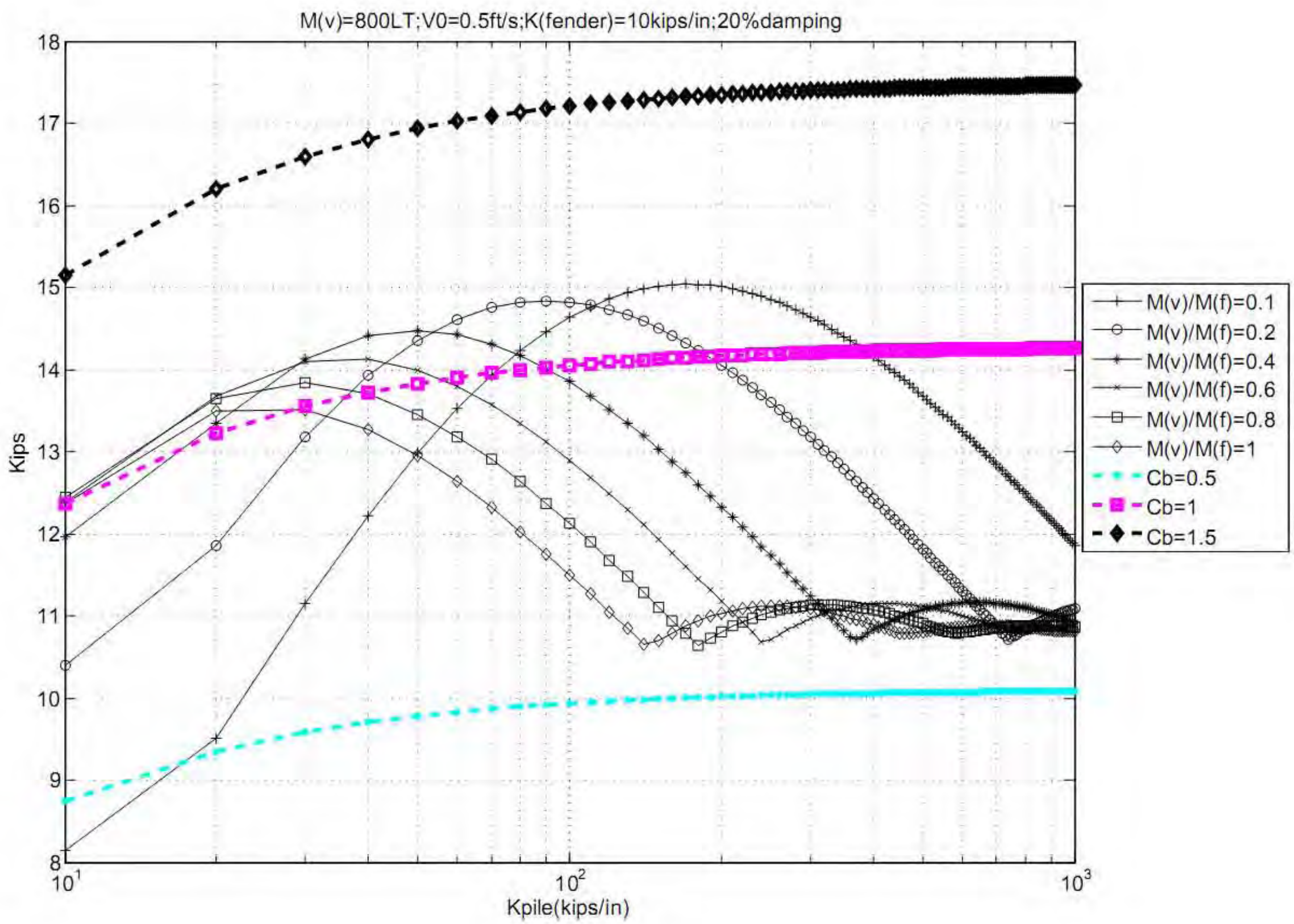
M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.97 Displacement of the Piling System 1D-25a



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.98 Displacement of the Piling System 1D-25b



M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.99 Reaction Force of the Piling System 1D-25a

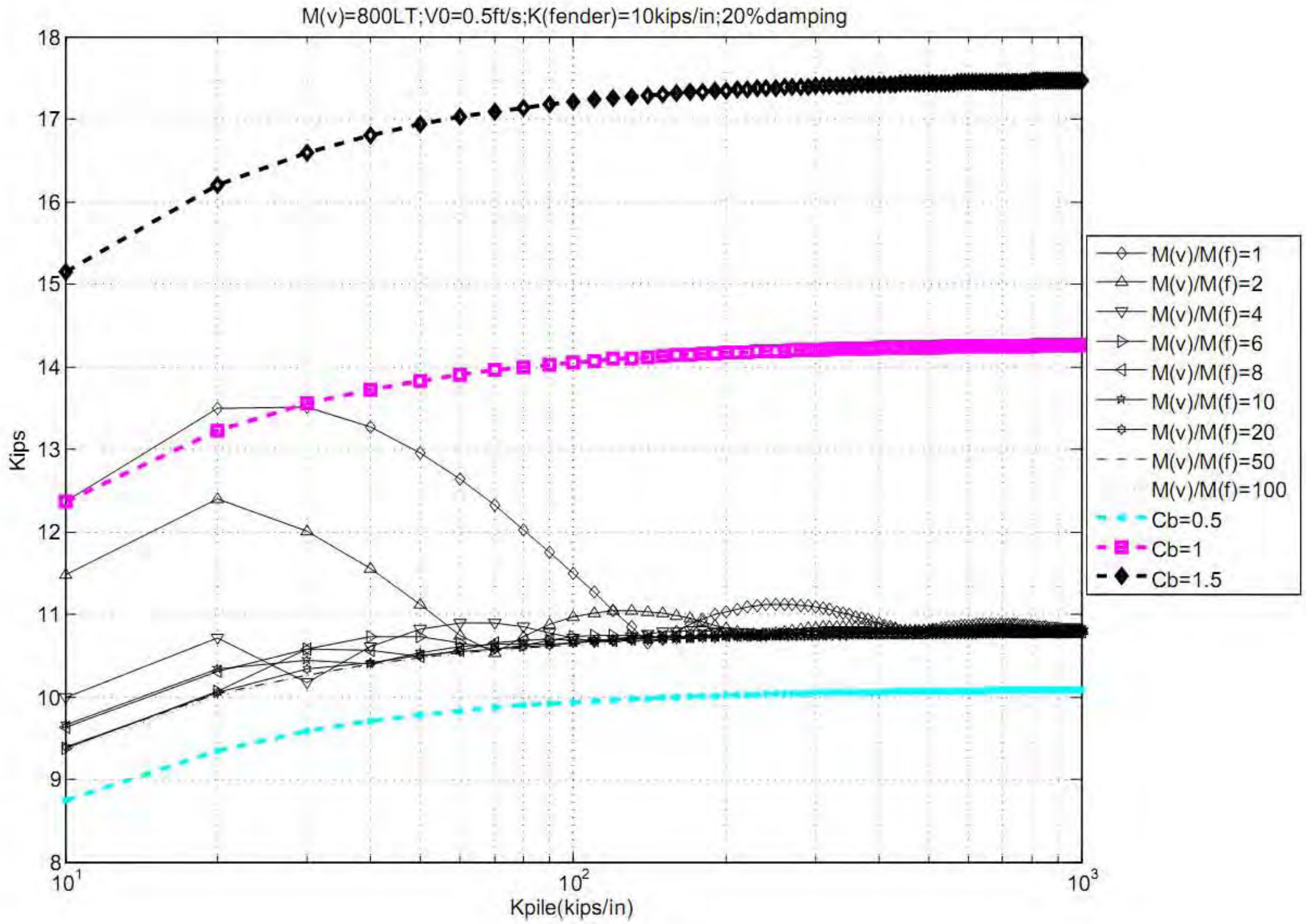

M(v)=800LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
18
17
16
15
14
13
12
11
10
9
8
Kips
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.100 Reaction Force of the Piling System 1D-25b

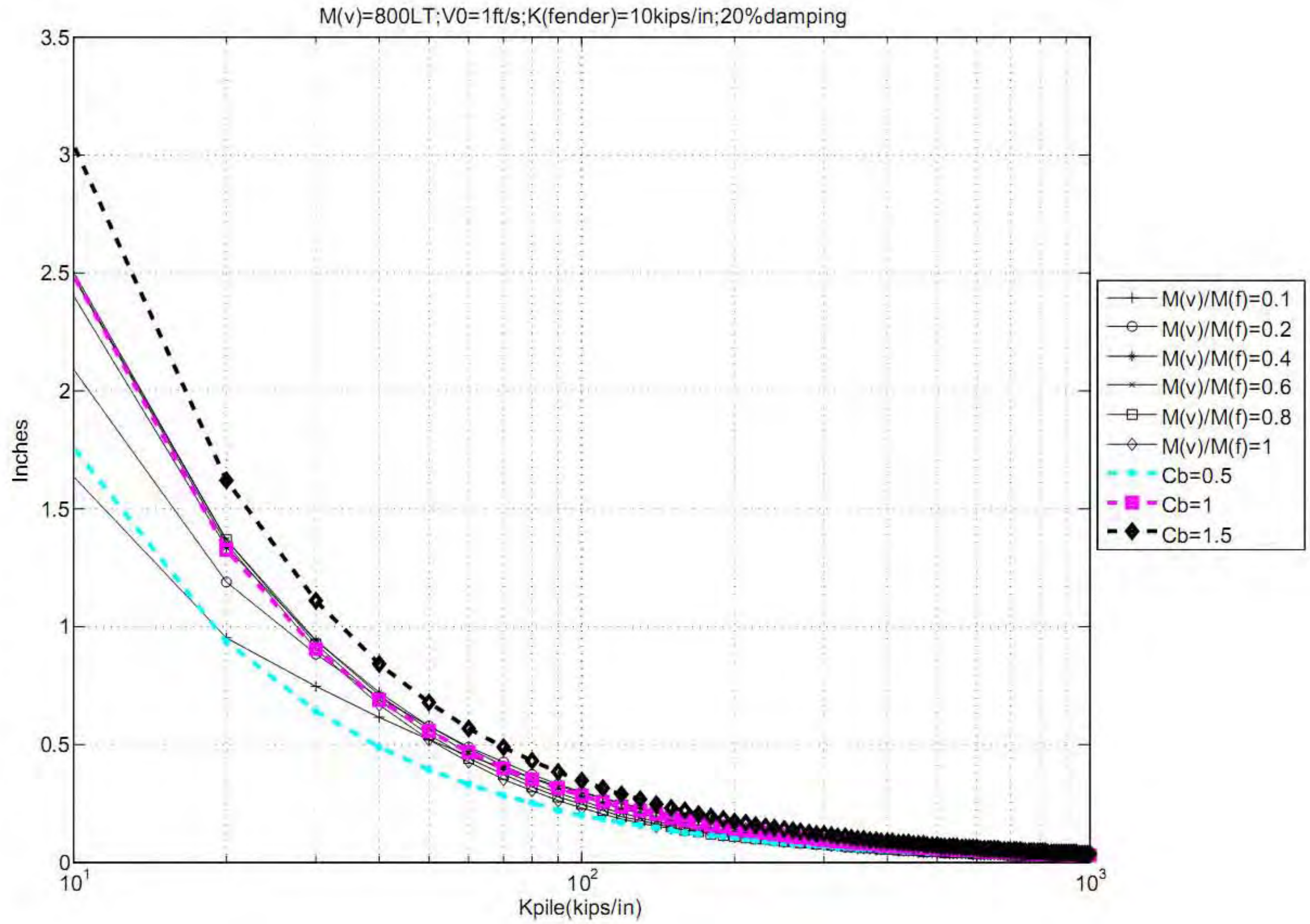
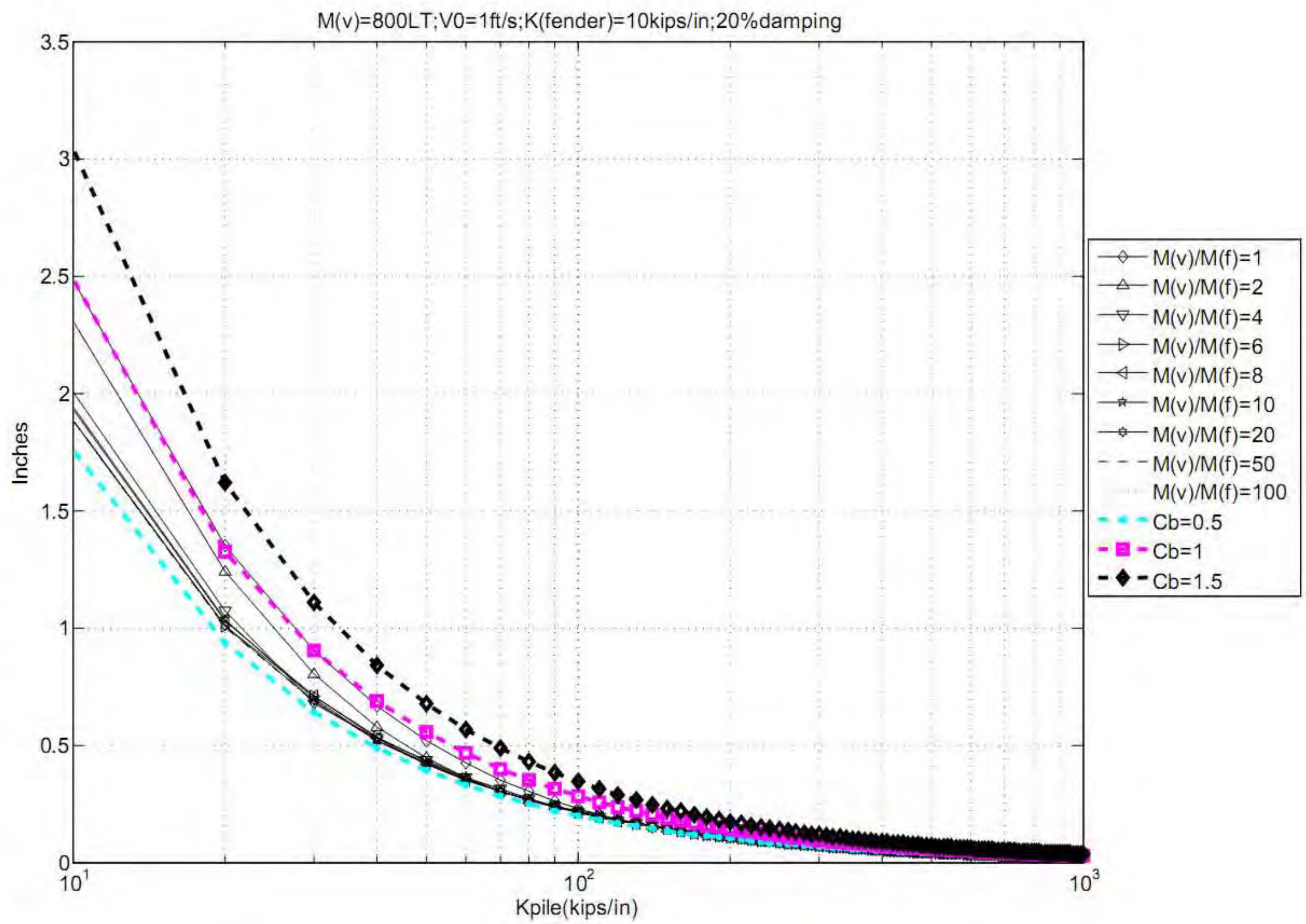
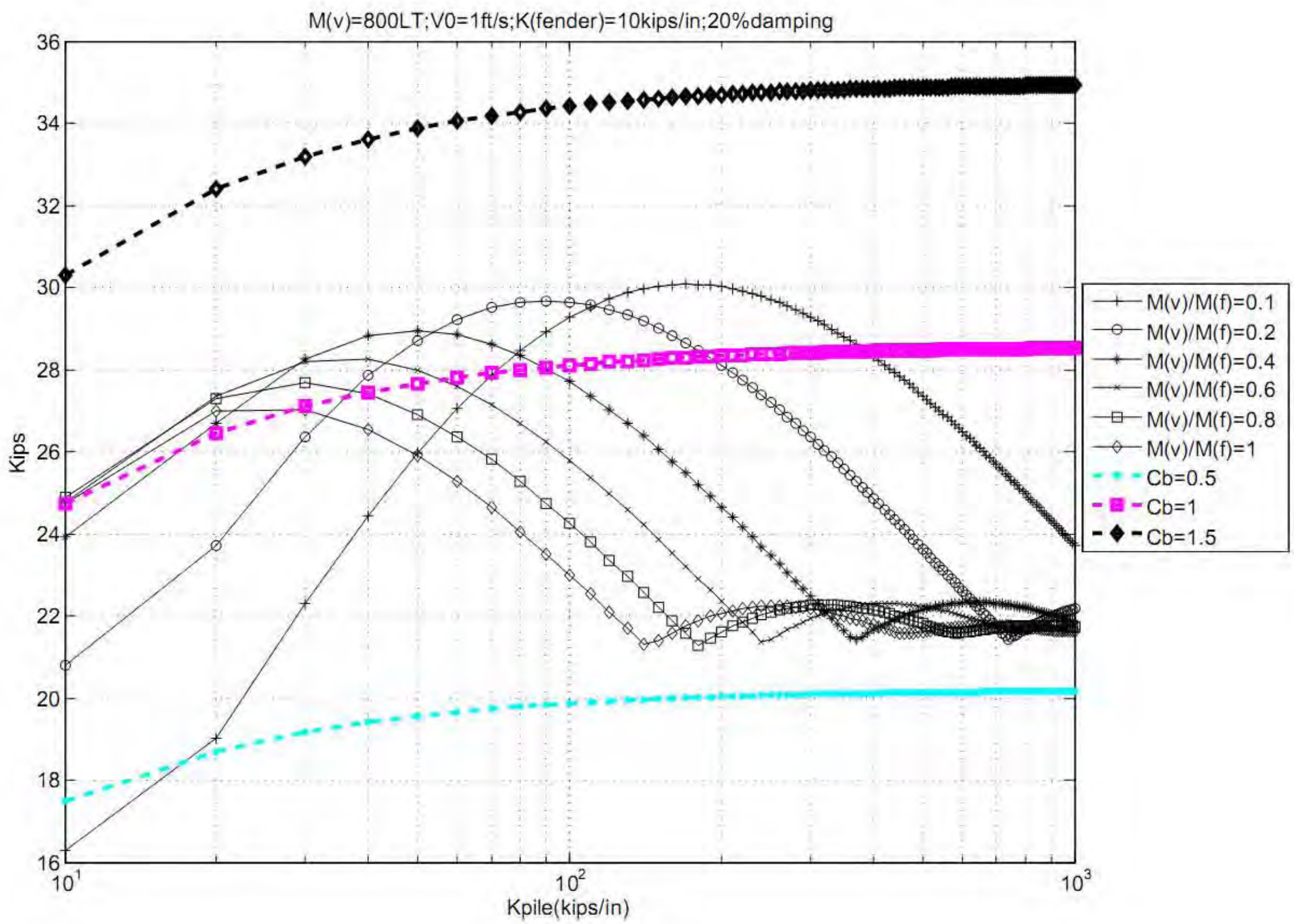

M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
3.5
3
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.101 Displacement of the Piling System 1D-26a



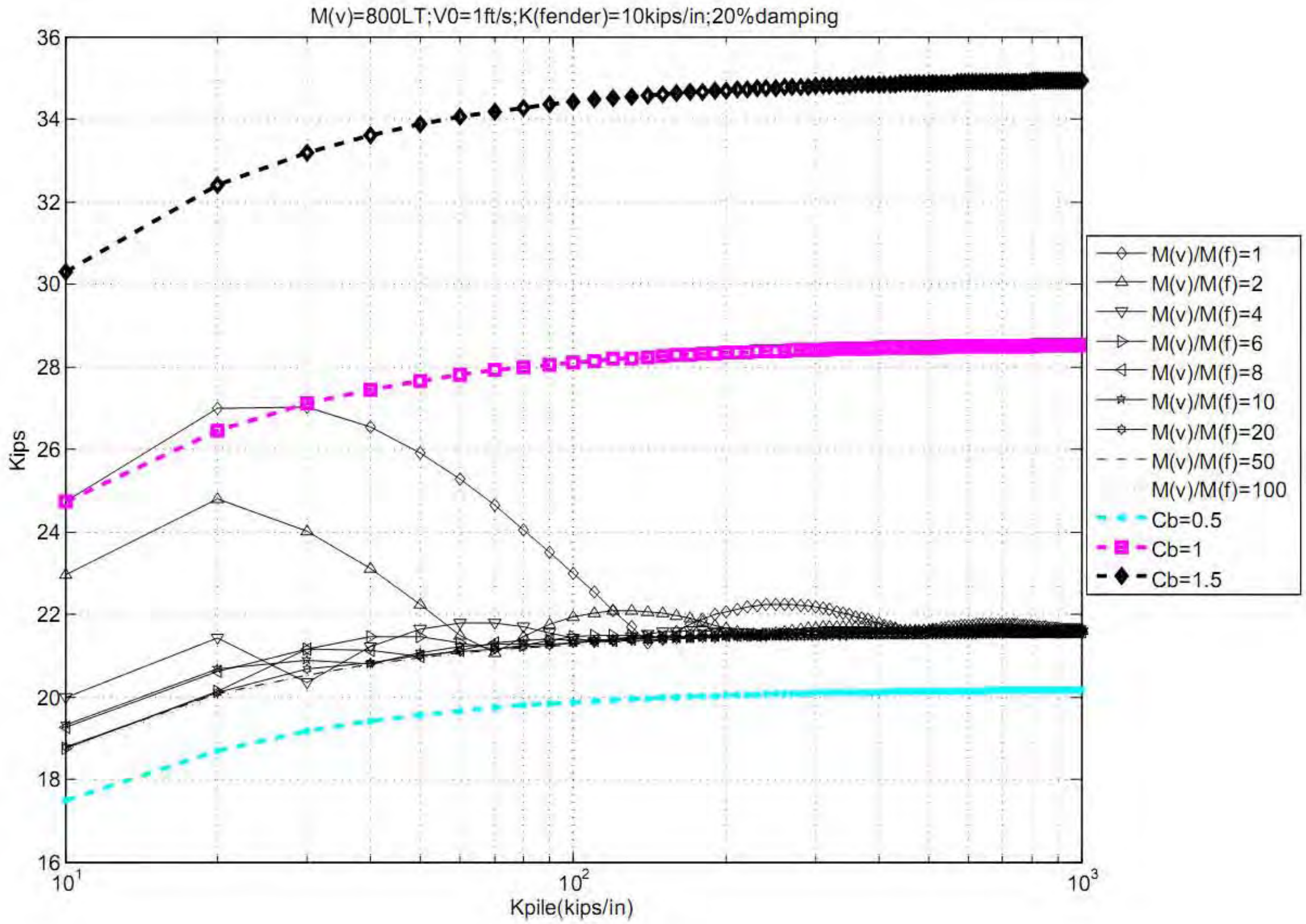
M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
3.5
3
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.102 Displacement of the Piling System 1D-26b



M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
36
34
32
30
28
26
24
22
20
18
16
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.103 Reaction Force of the Piling System 1D-26a



M(v)=800LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.104 Reaction Force of the Piling System 1D-26b

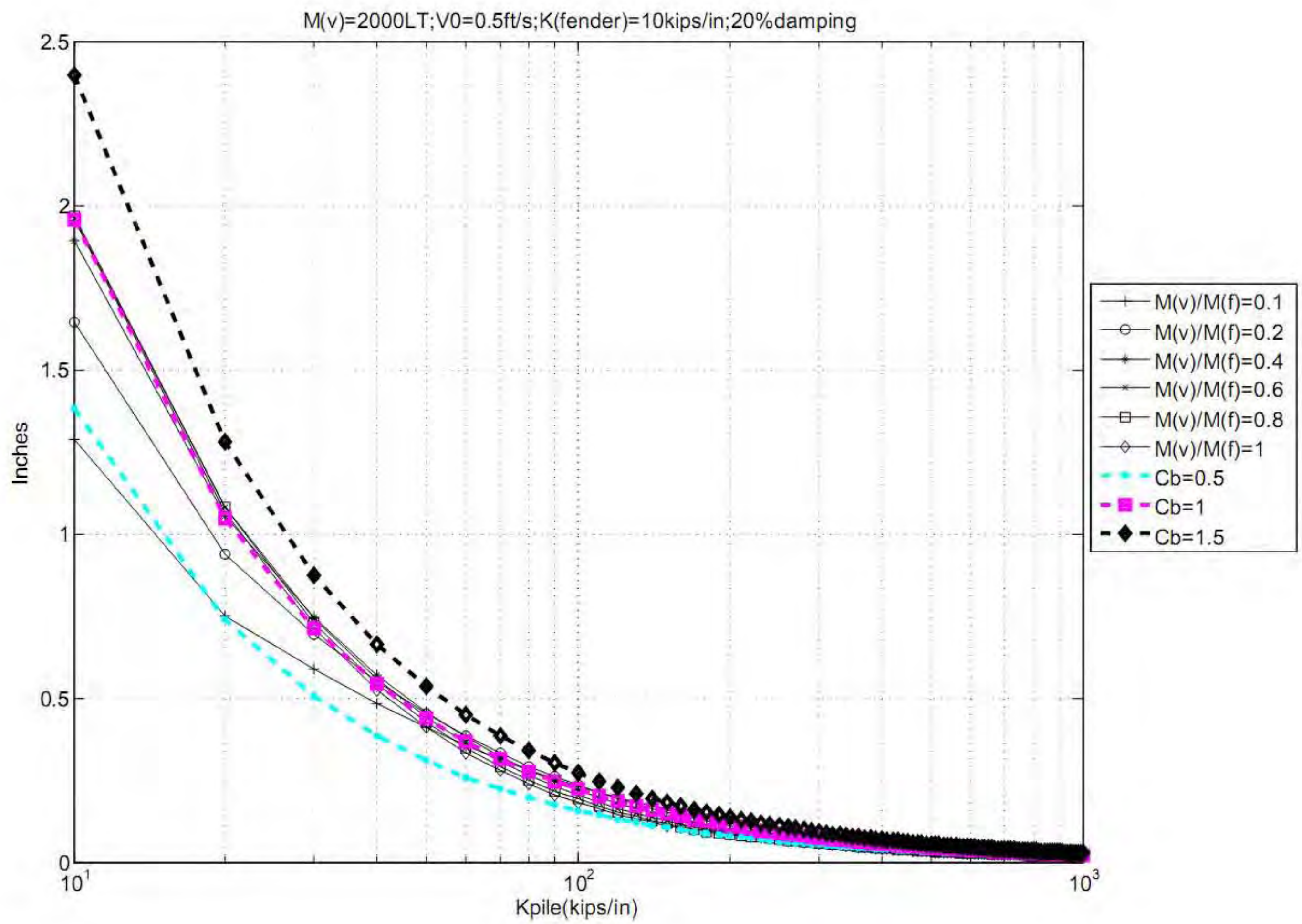

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3

Fig. A.105 Displacement of the Piling System 1D-27a

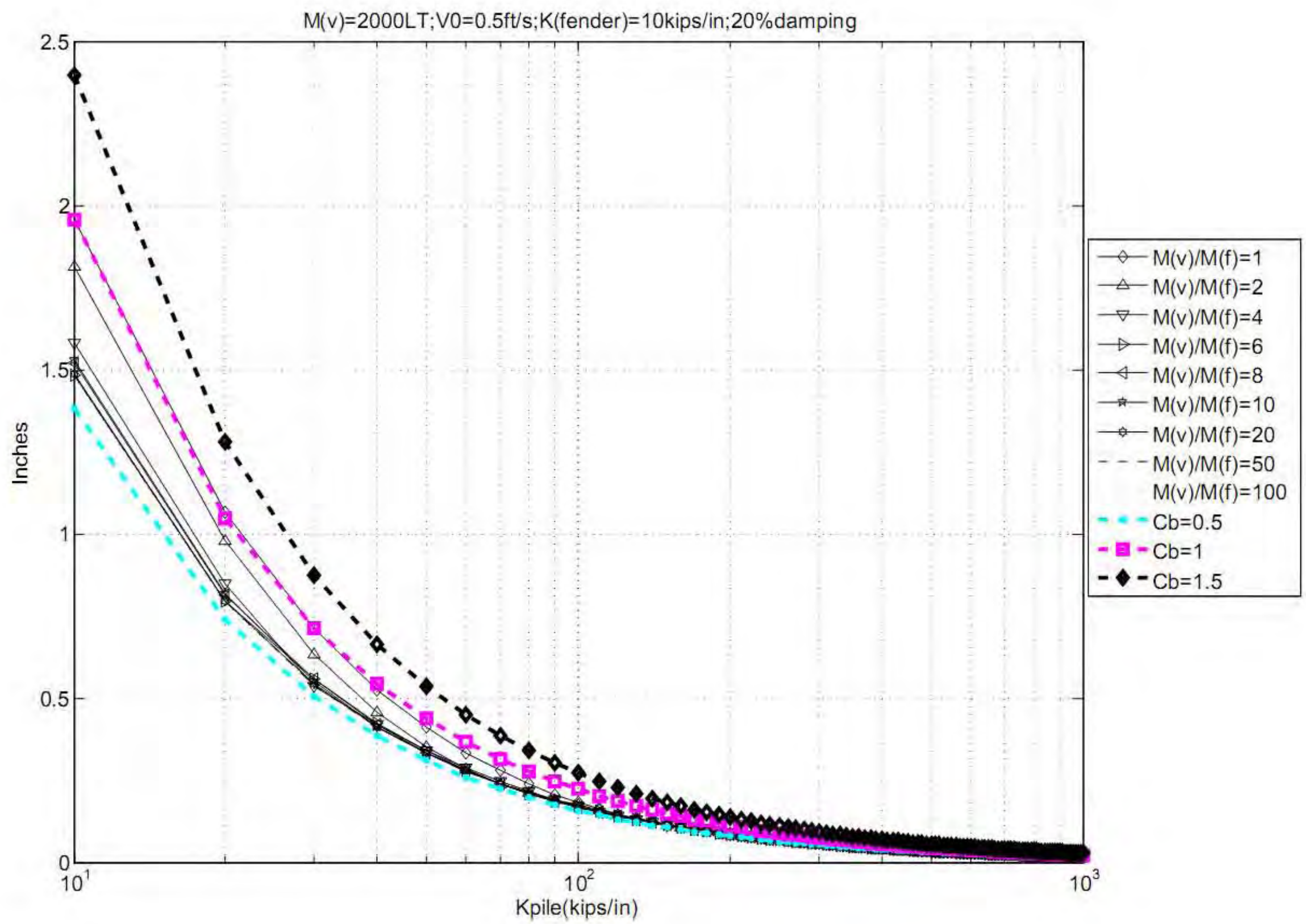
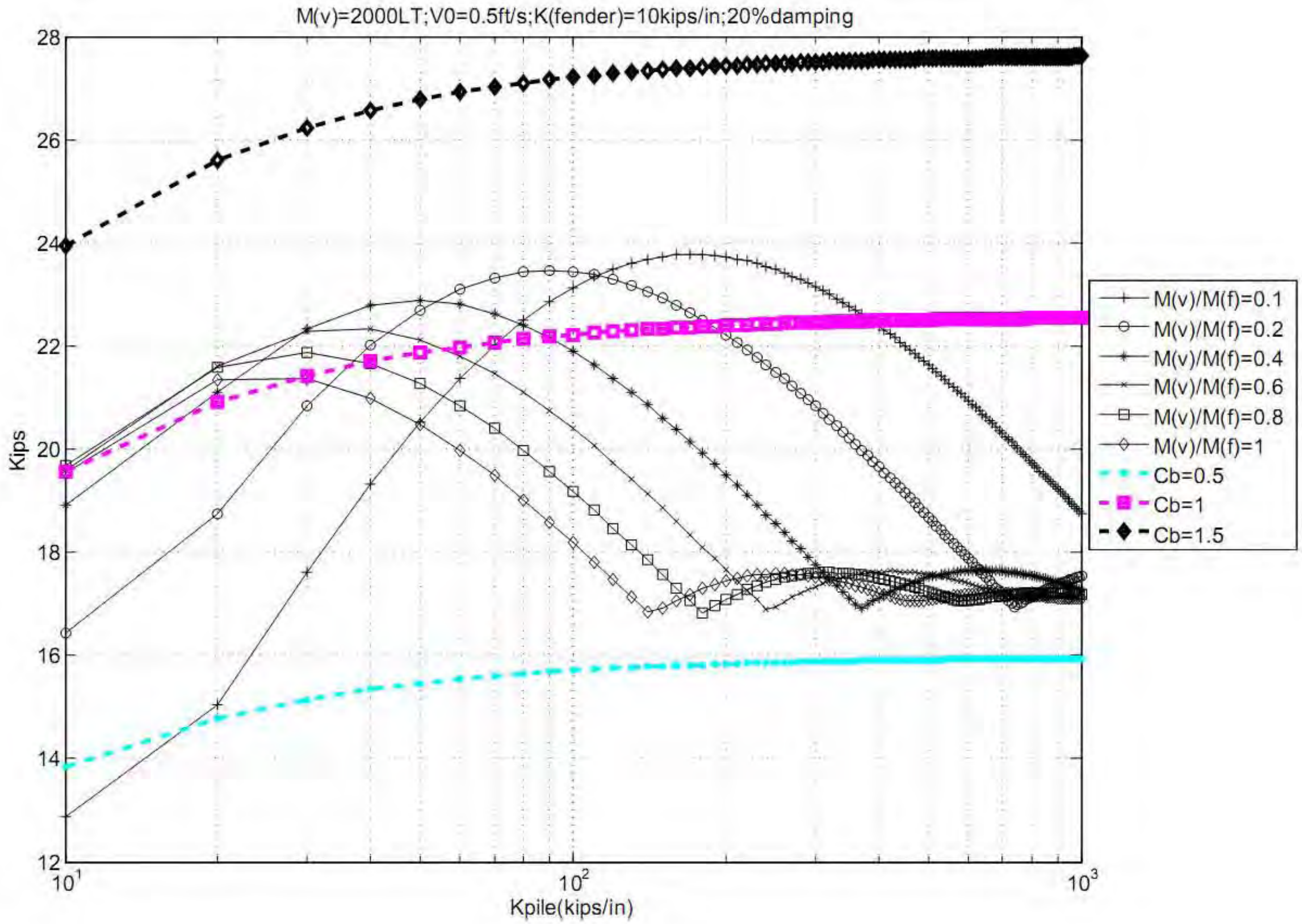
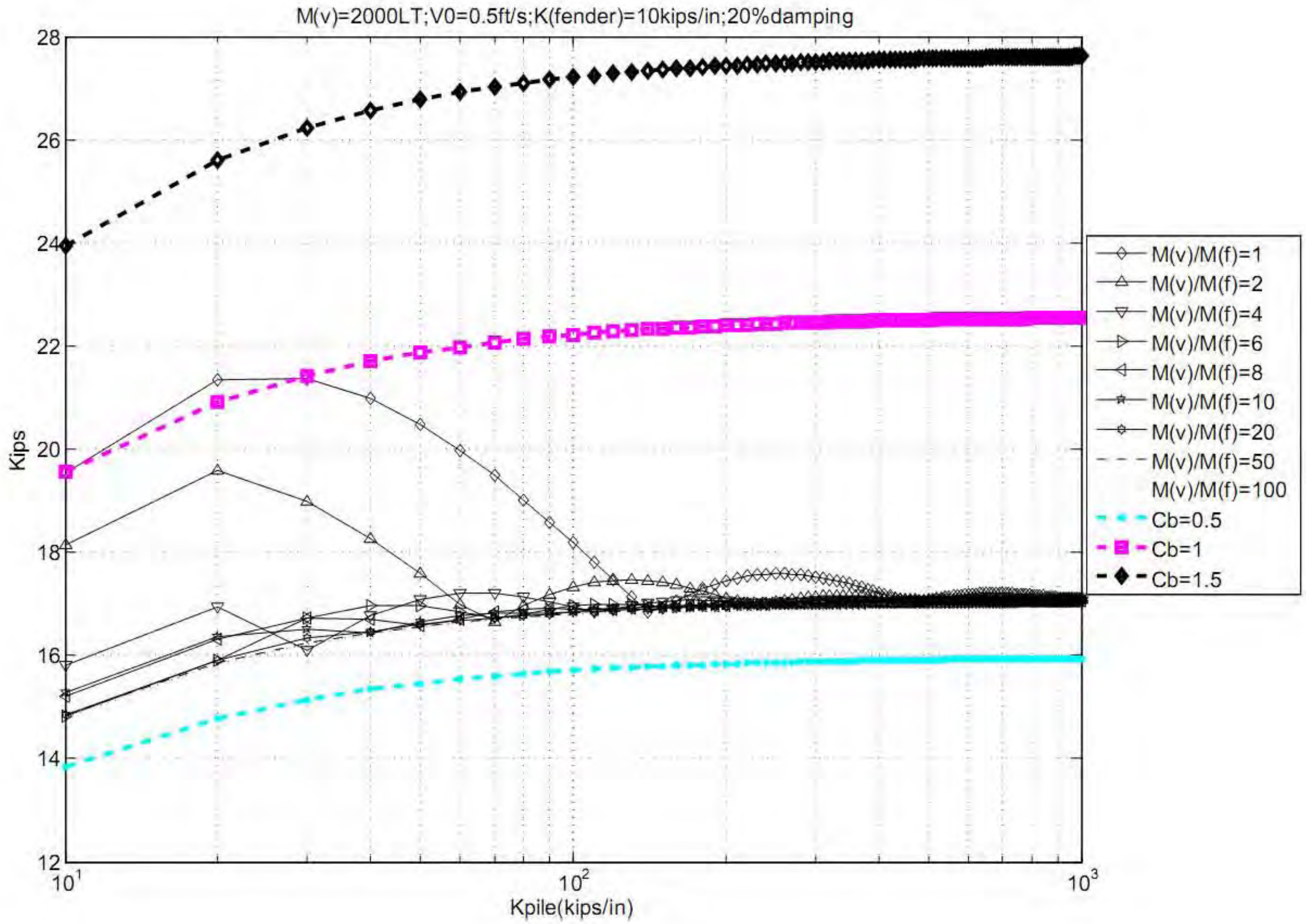

M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.106 Displacement of the Piling System 1D-27b



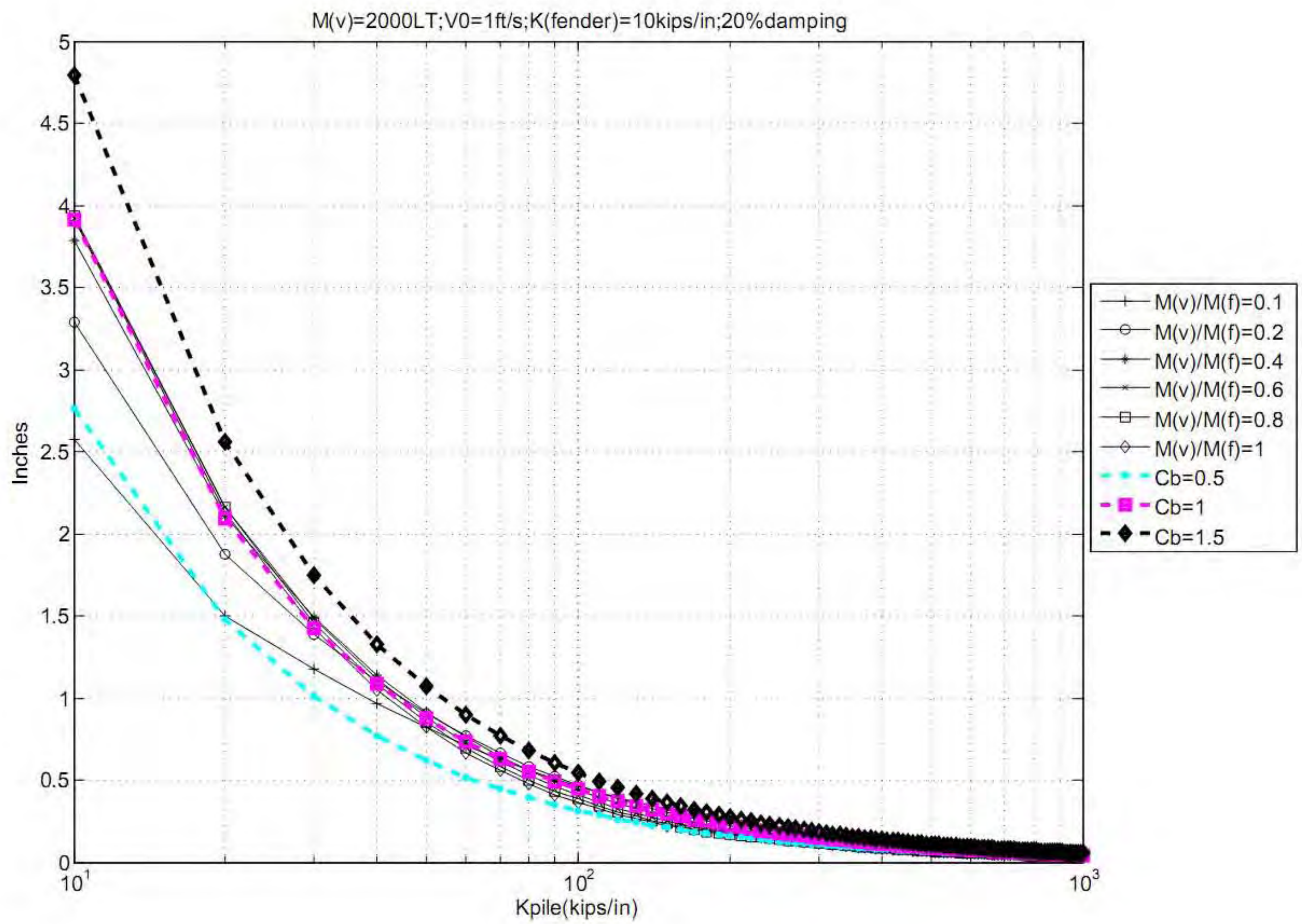
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.107 Reaction Force of the Piling System 1D-27a



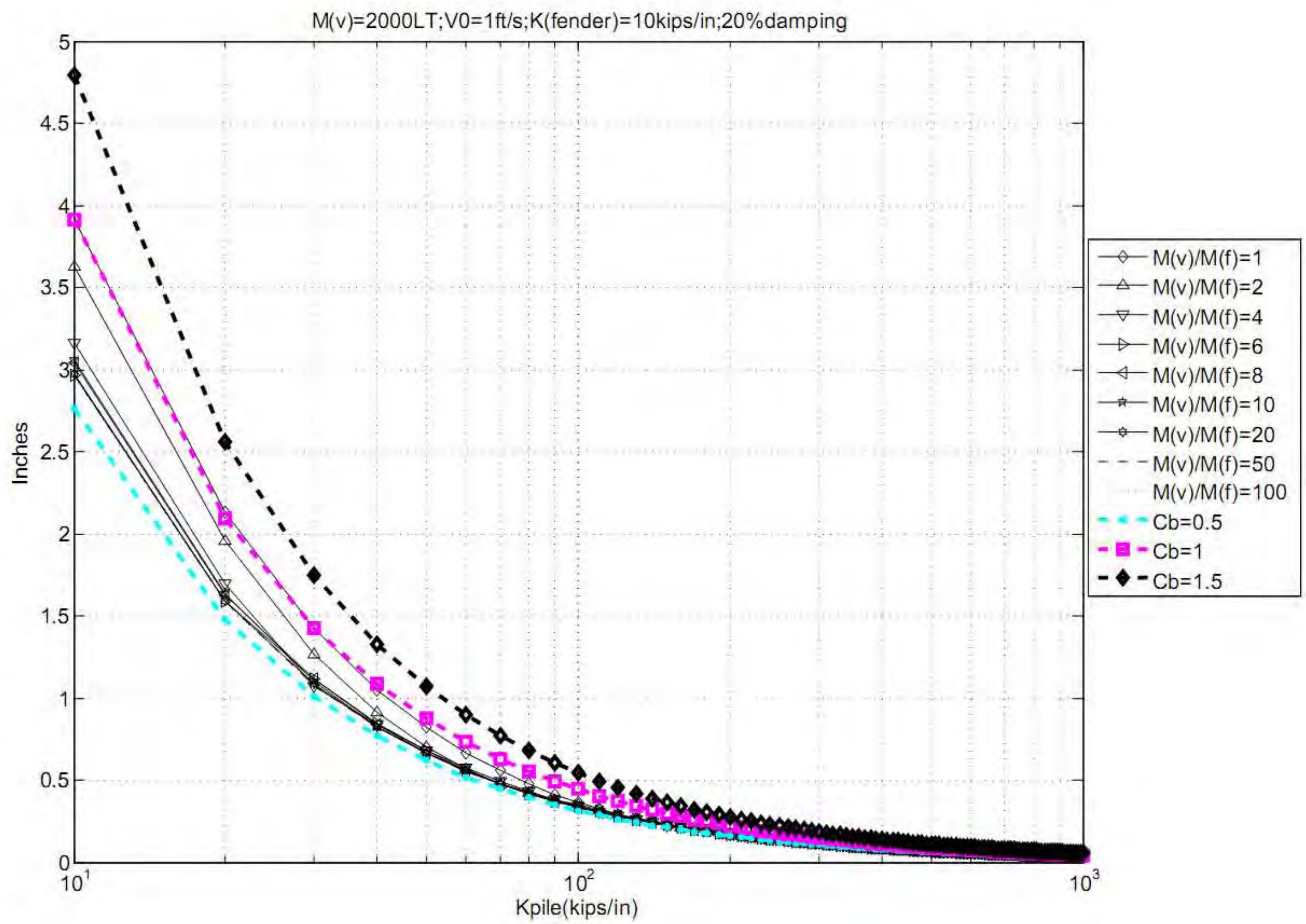
M(v)=2000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
28
26
24
22
20
18
16
14
12
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.108 Reaction Force of the Piling System 1D-27b



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.109 Displacement of the Piling System 1D-28a



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.110 Displacement of the Piling System 1D-28b

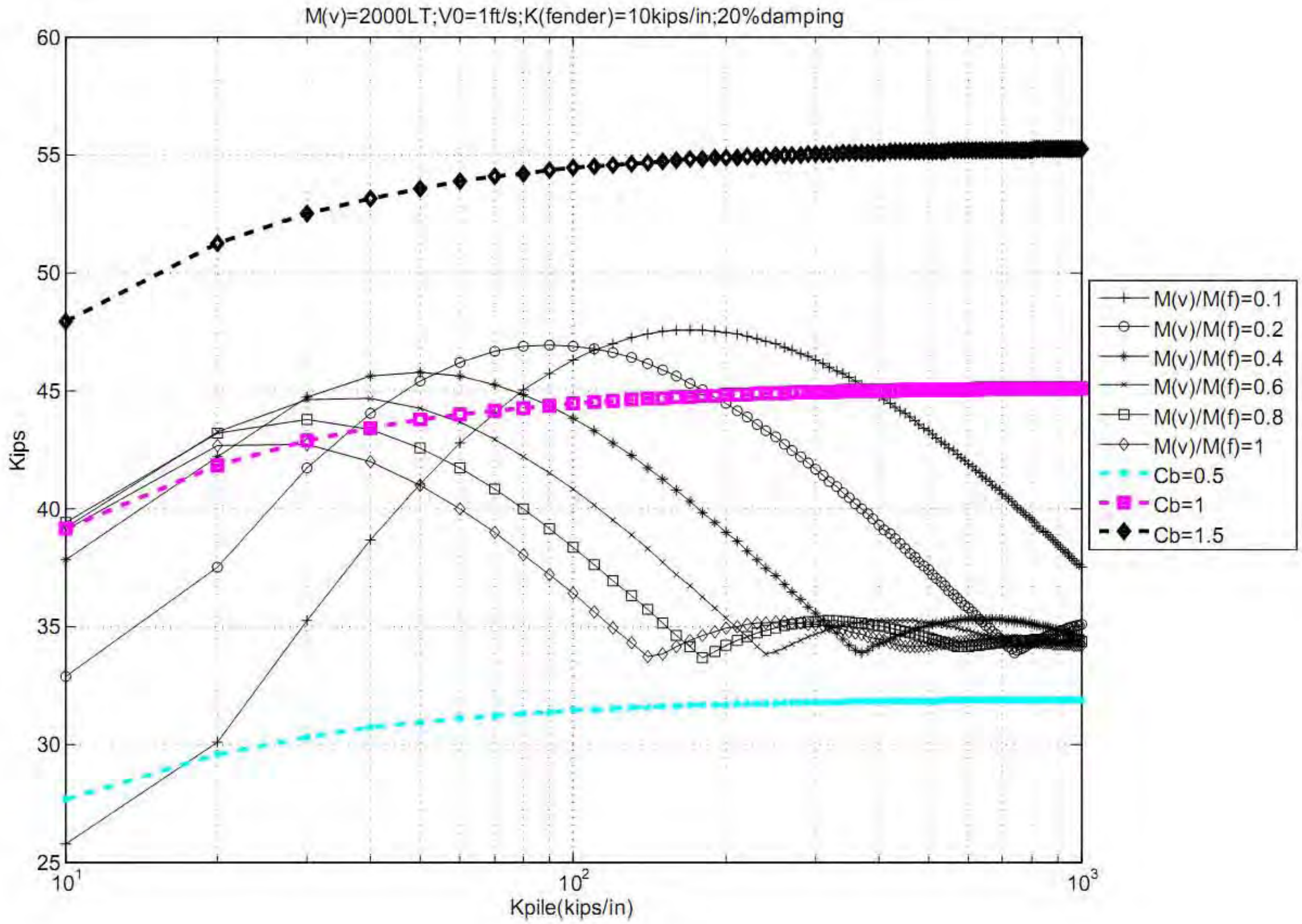
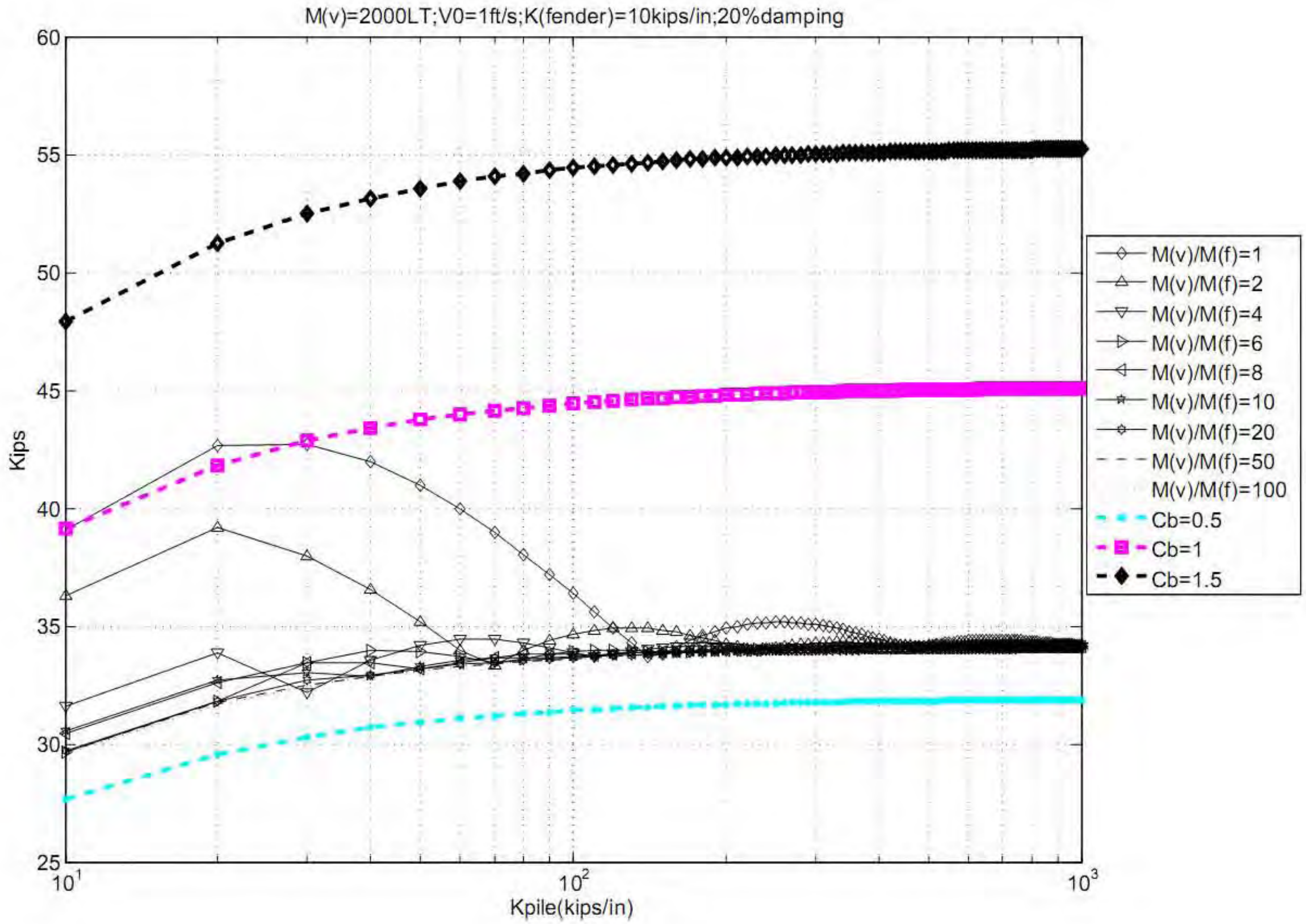

M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.111 Reaction Force of the Piling System 1D-28a



M(v)=2000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.112 Reaction Force of the Piling System 1D-28b

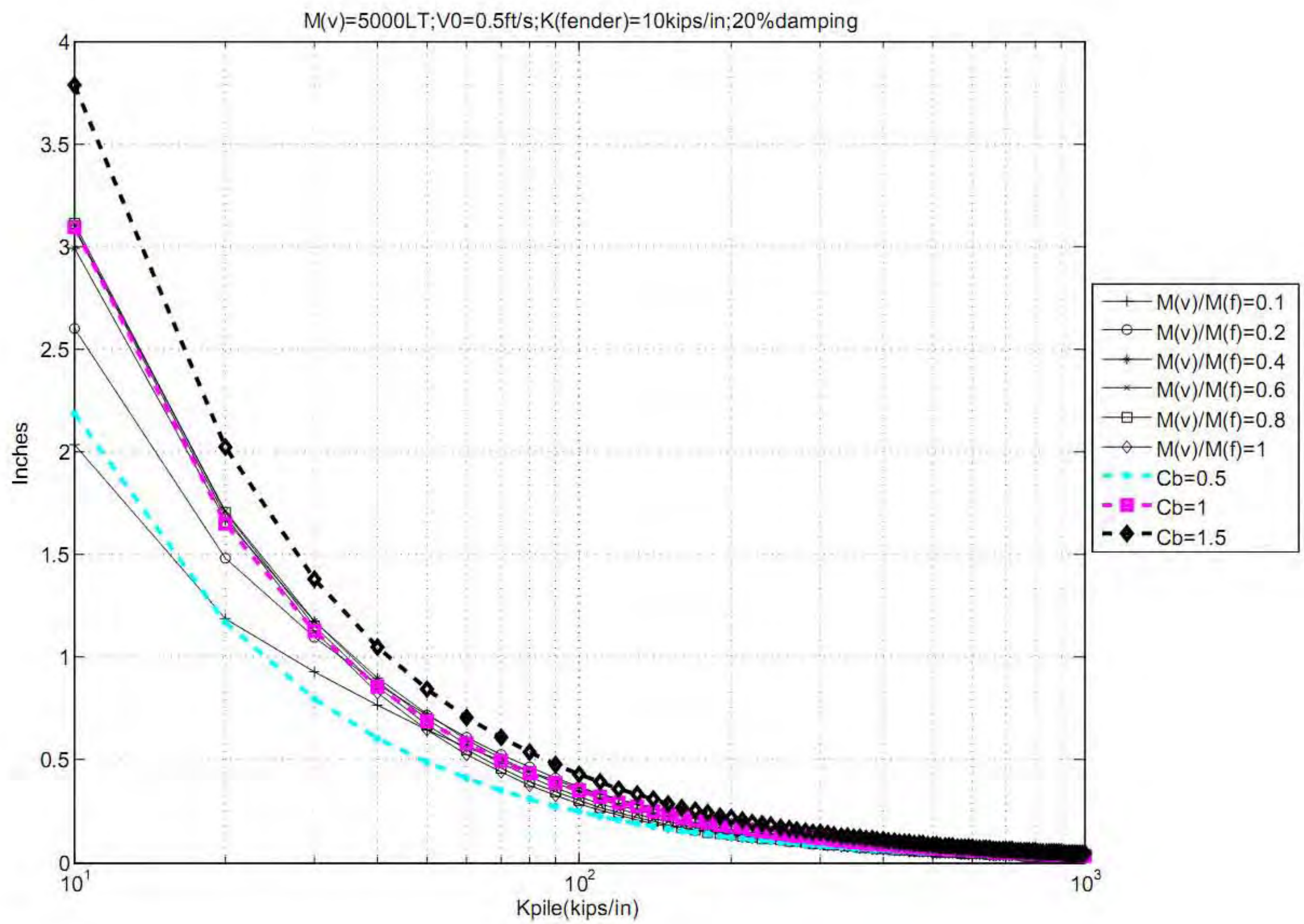
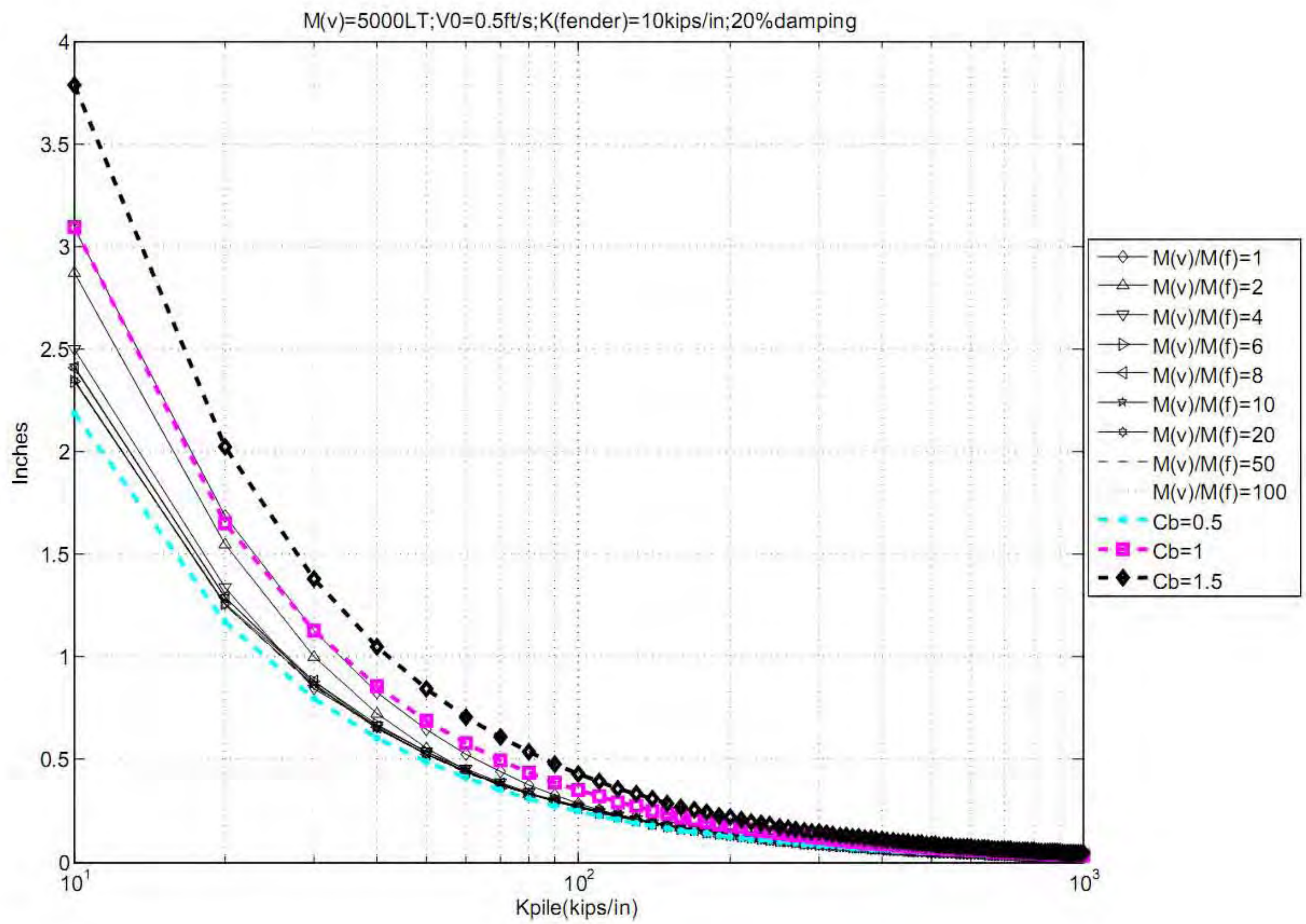
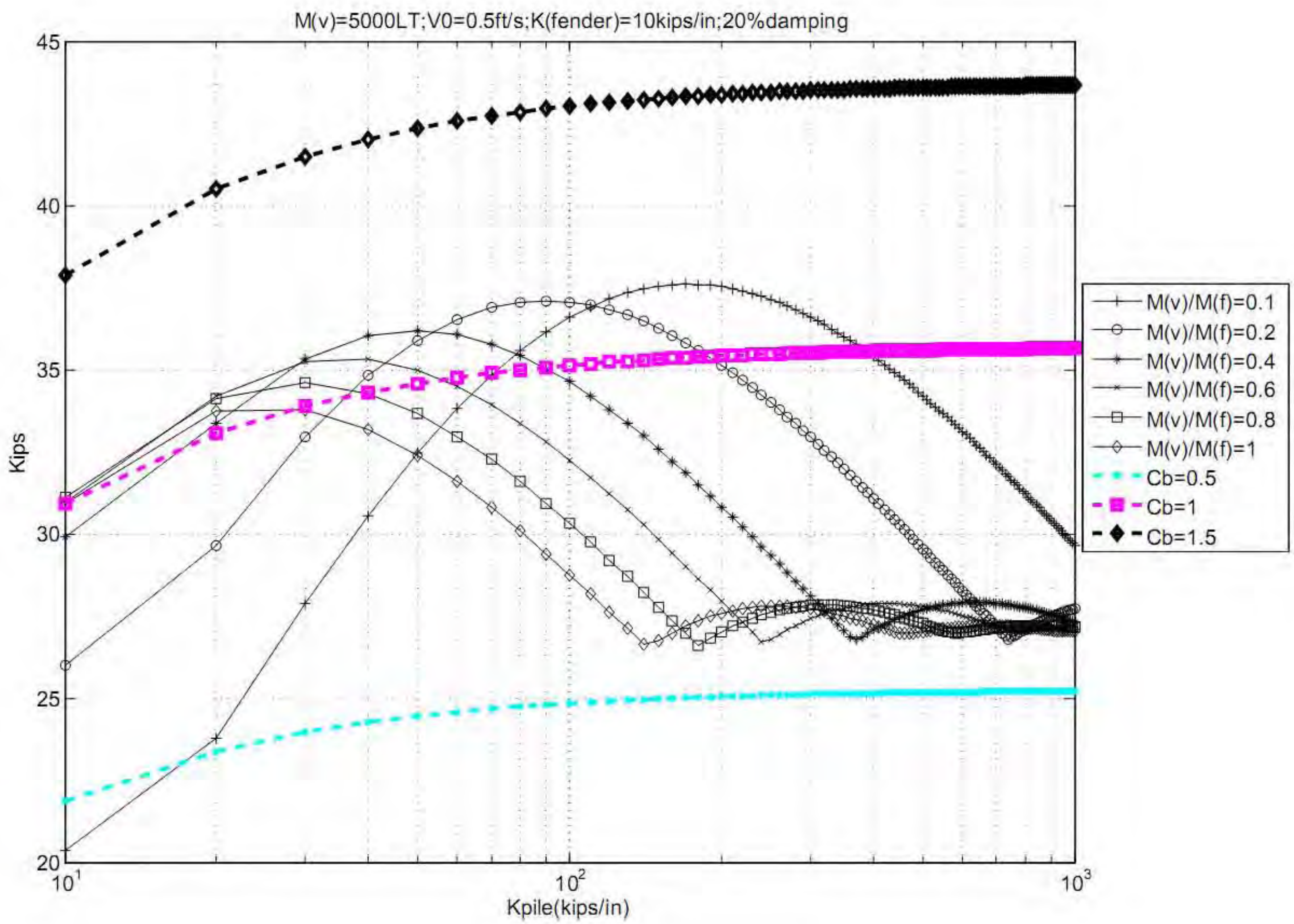

M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.113 Displacement of the Piling System 1D-29a



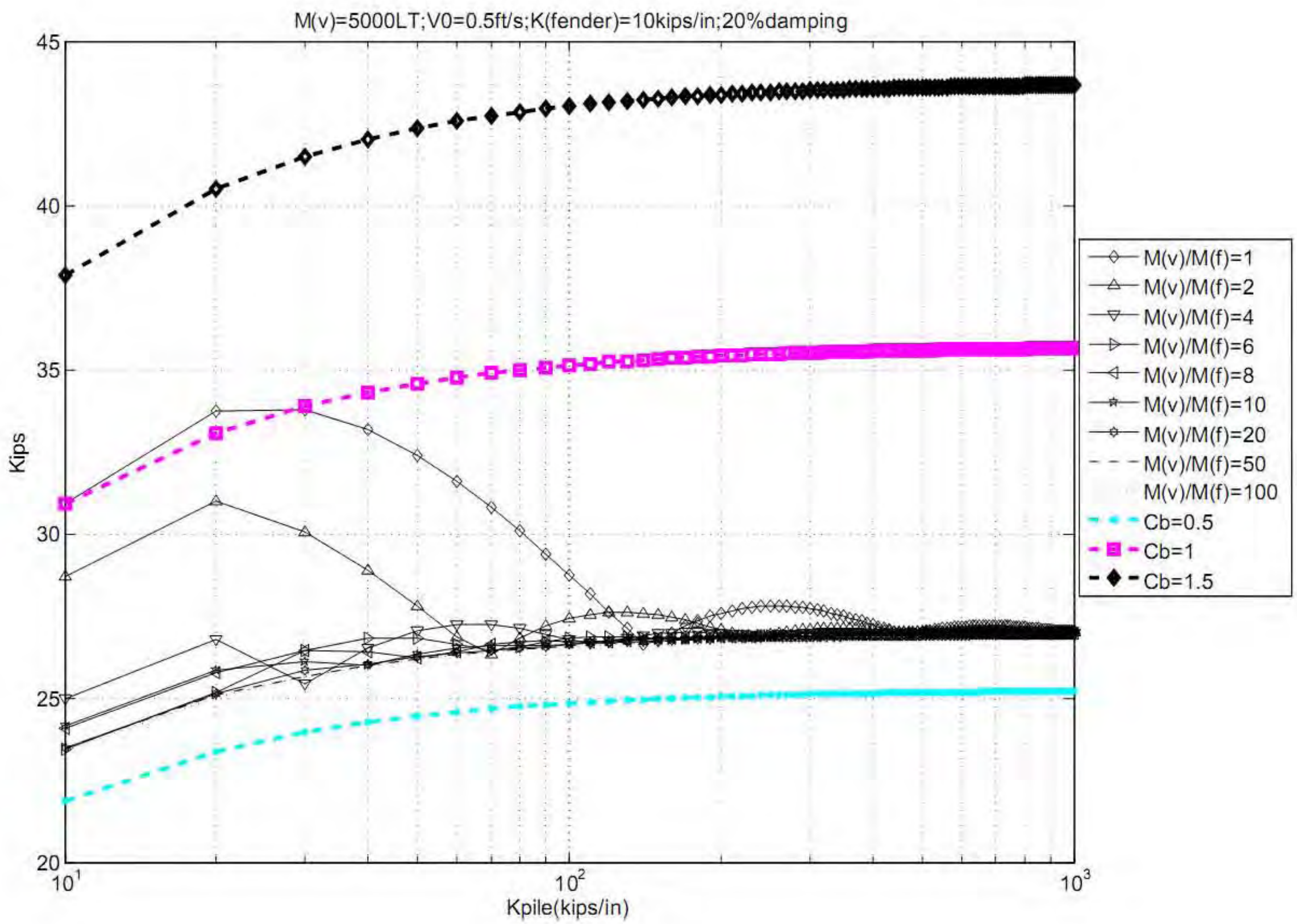
M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
4
3.5
3
2.5
2
1.5
1
0.5
0
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.114 Displacement of the Piling System 1D-29b



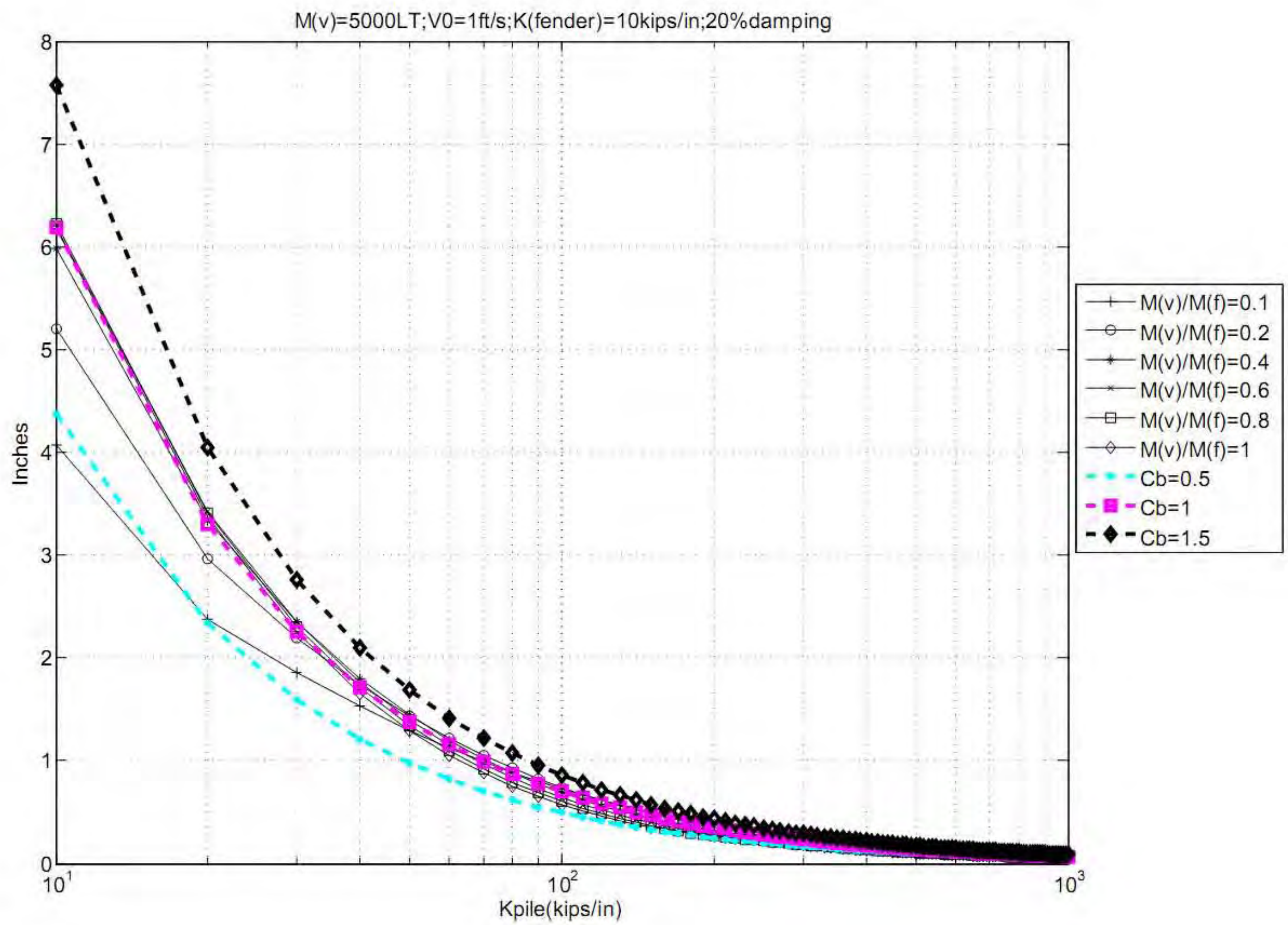
M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.115 Reaction Force of the Piling System 1D-29a



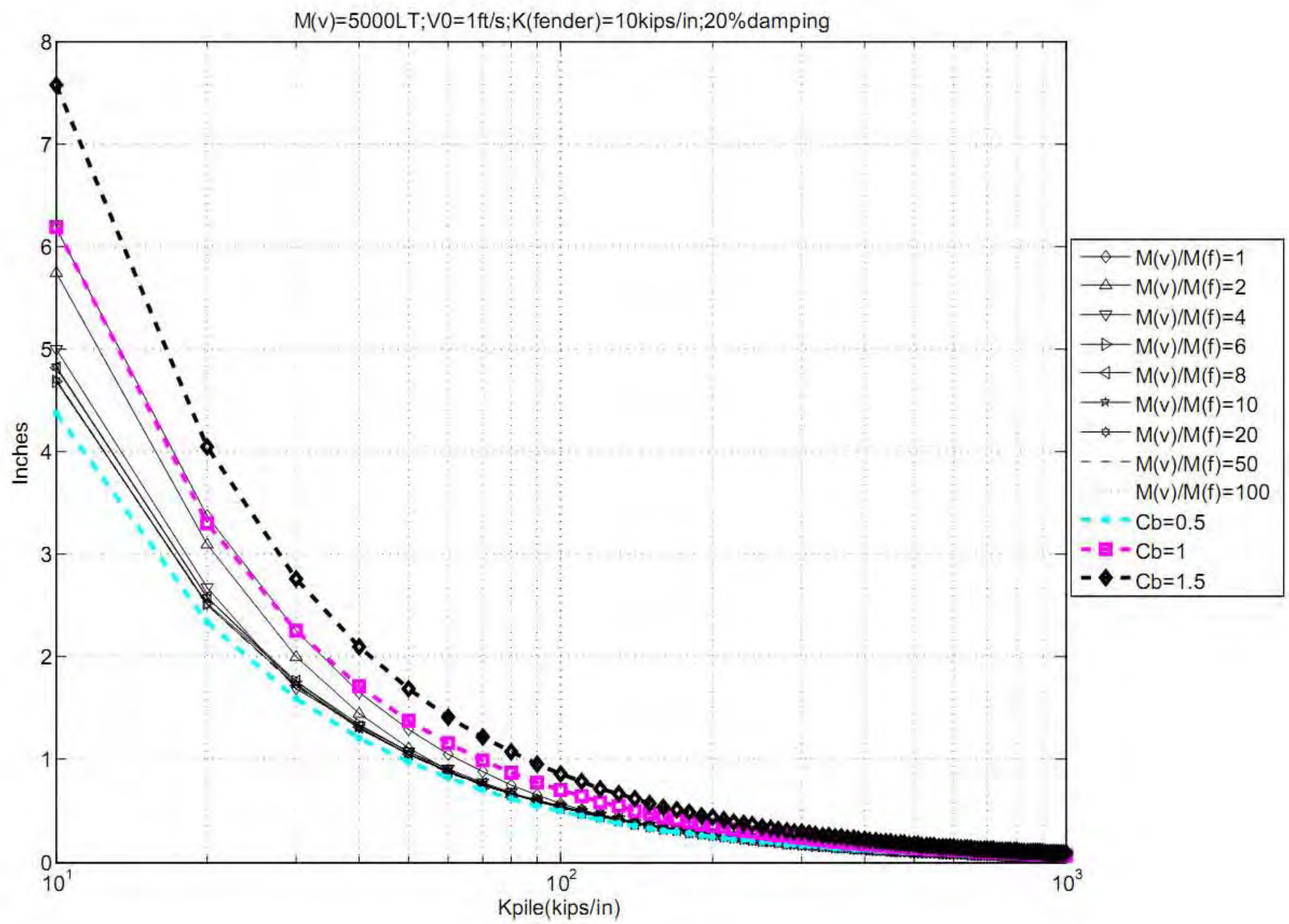
M(v)=5000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
45
40
35
30
25
20
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.116 Reaction Force of the Piling System 1D-29b



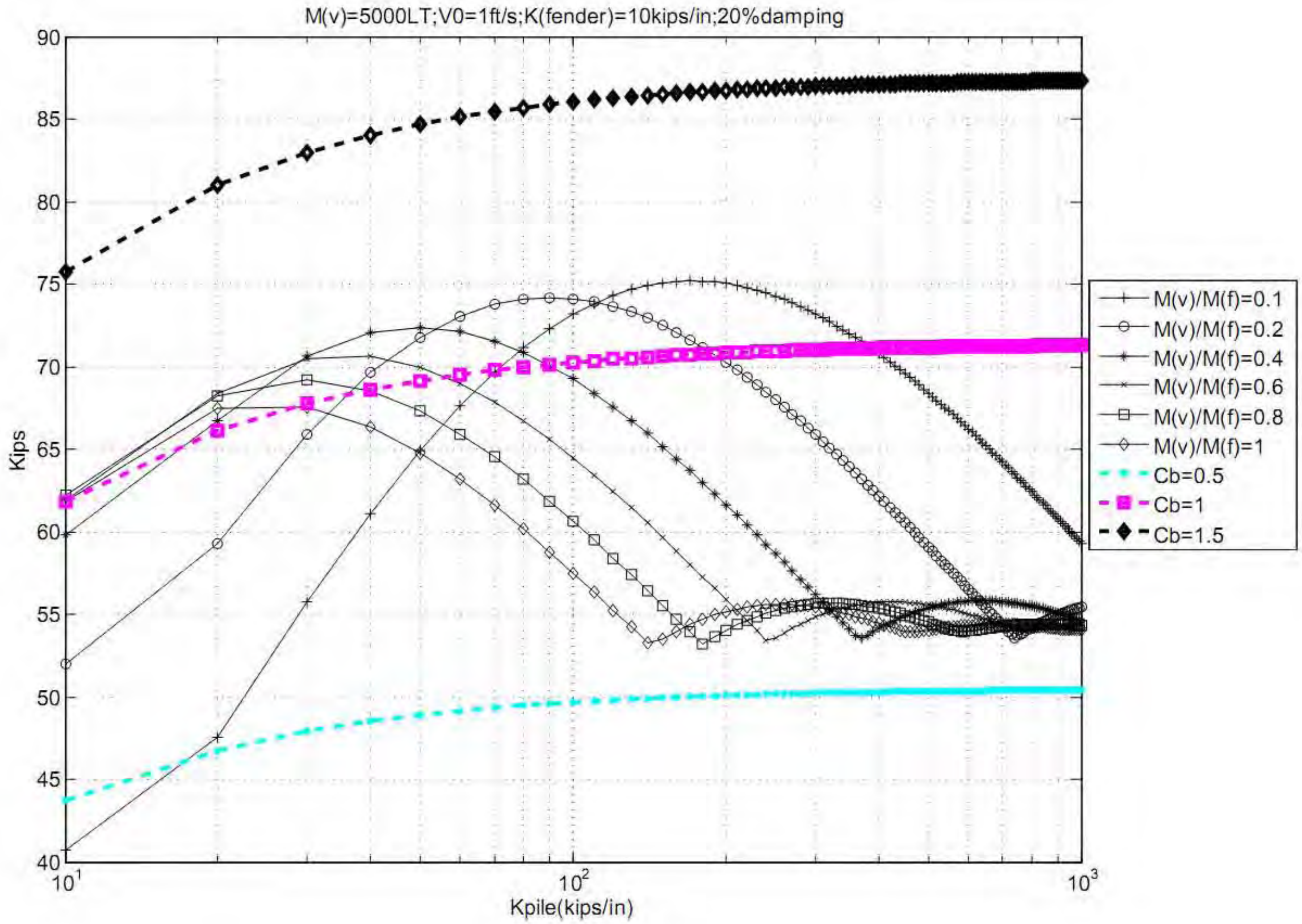
M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.117 Displacement of the Piling System 1D-30a



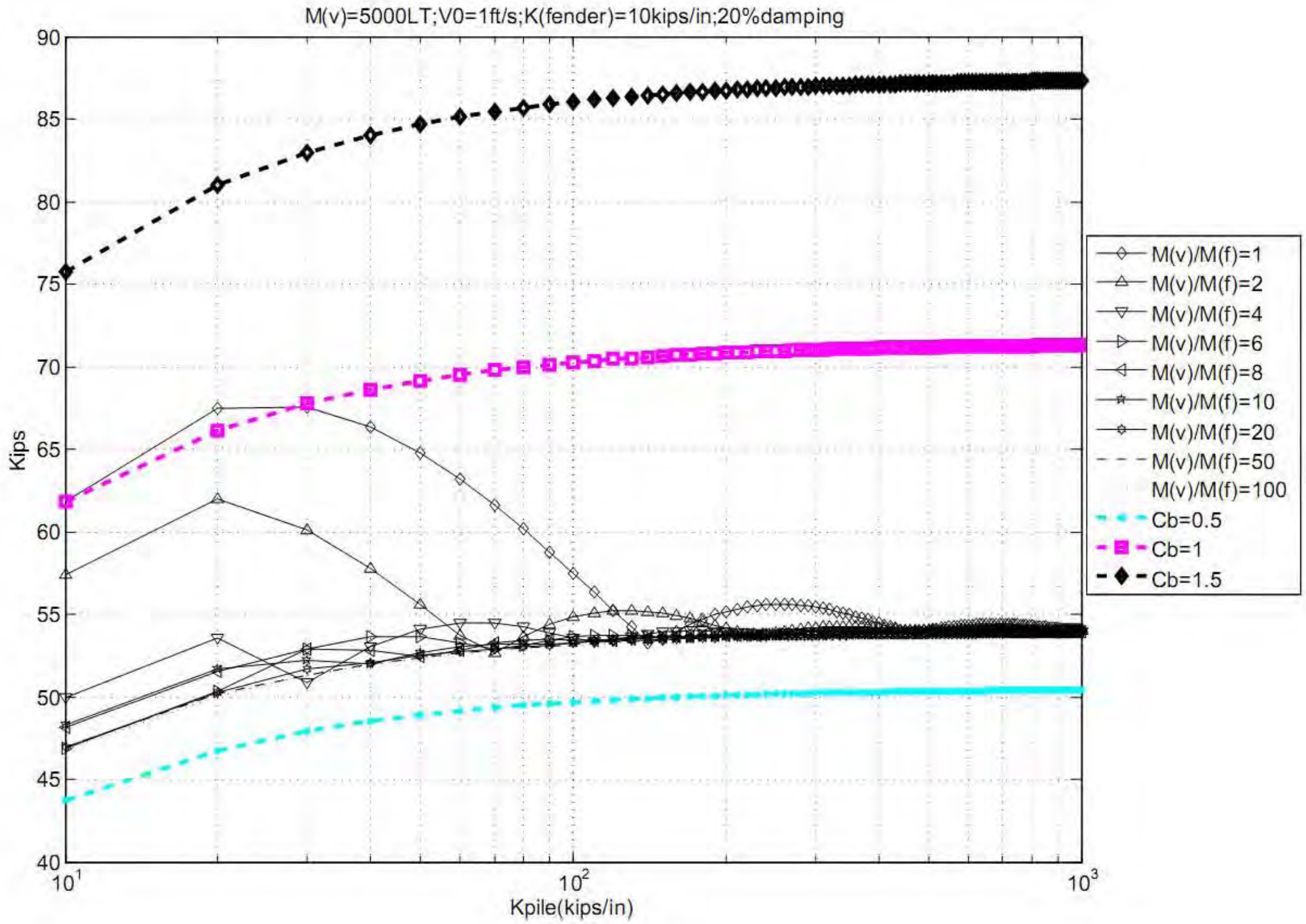
M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.118 Displacement of the Piling System 1D-30b



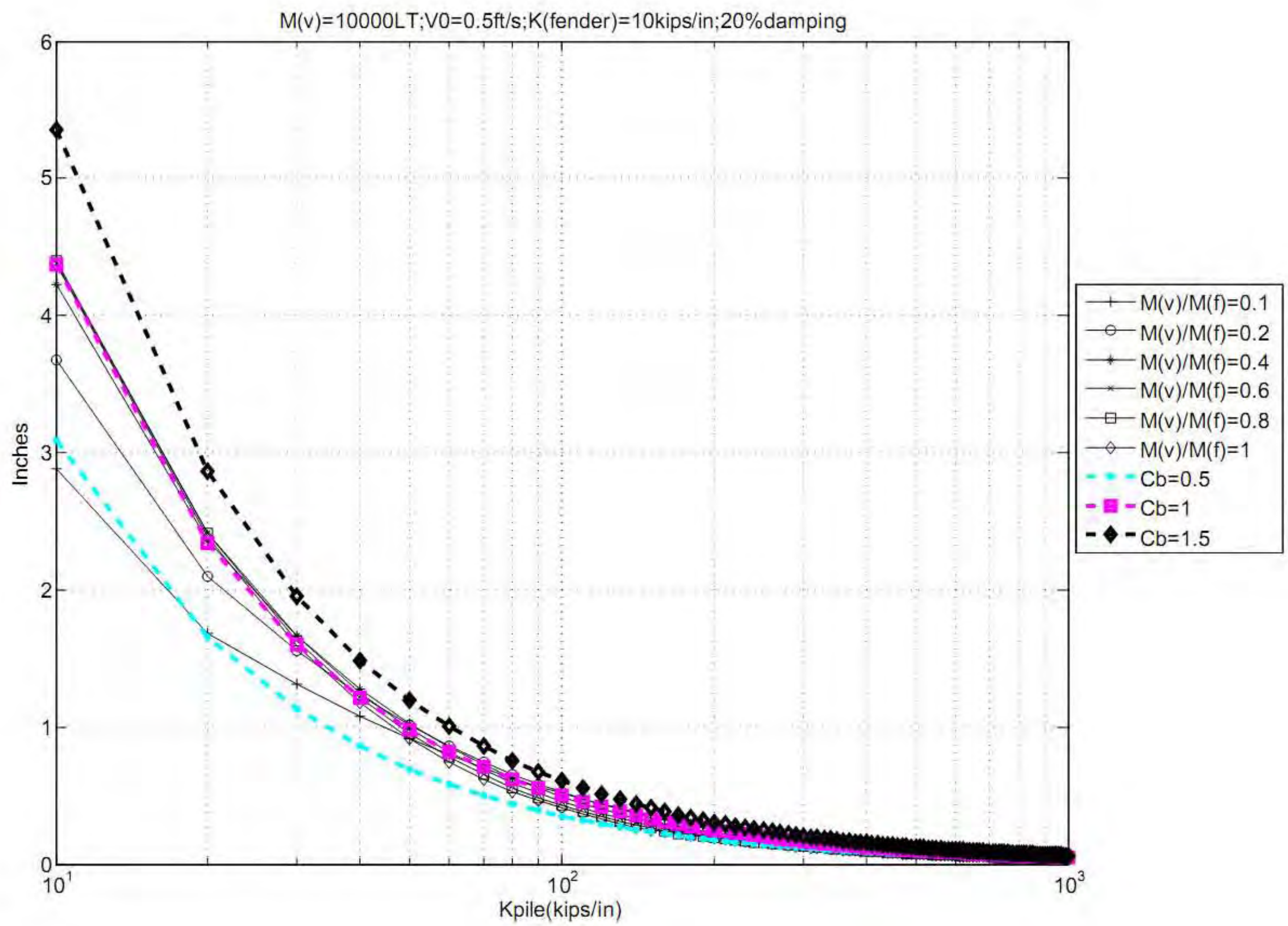
M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
90
85
80
75
70
65
60
55
50
45
40
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.119 Reaction Force of the Piling System 1D-30a



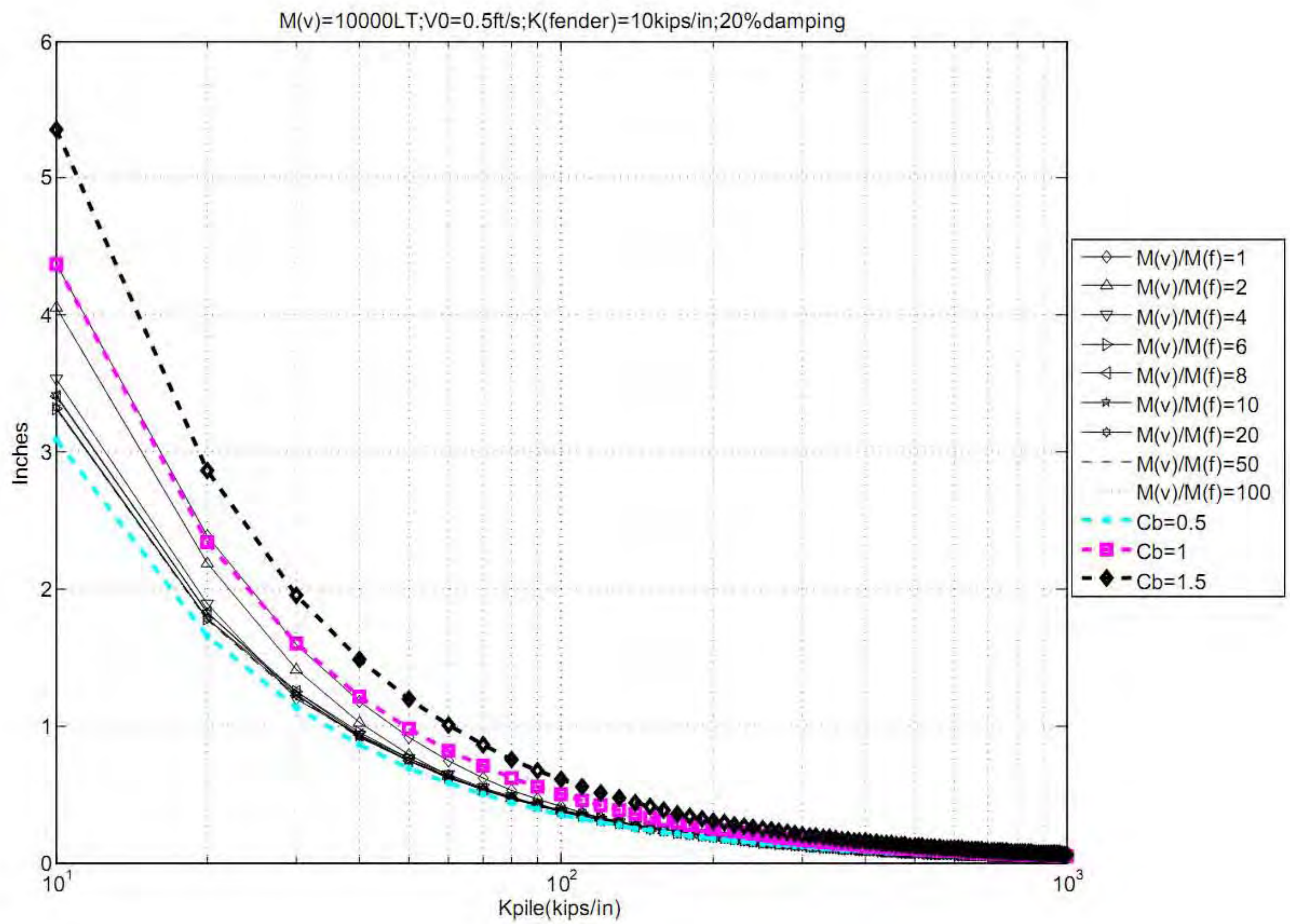
M(v)=5000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.120 Reaction Force of the Piling System 1D-30b



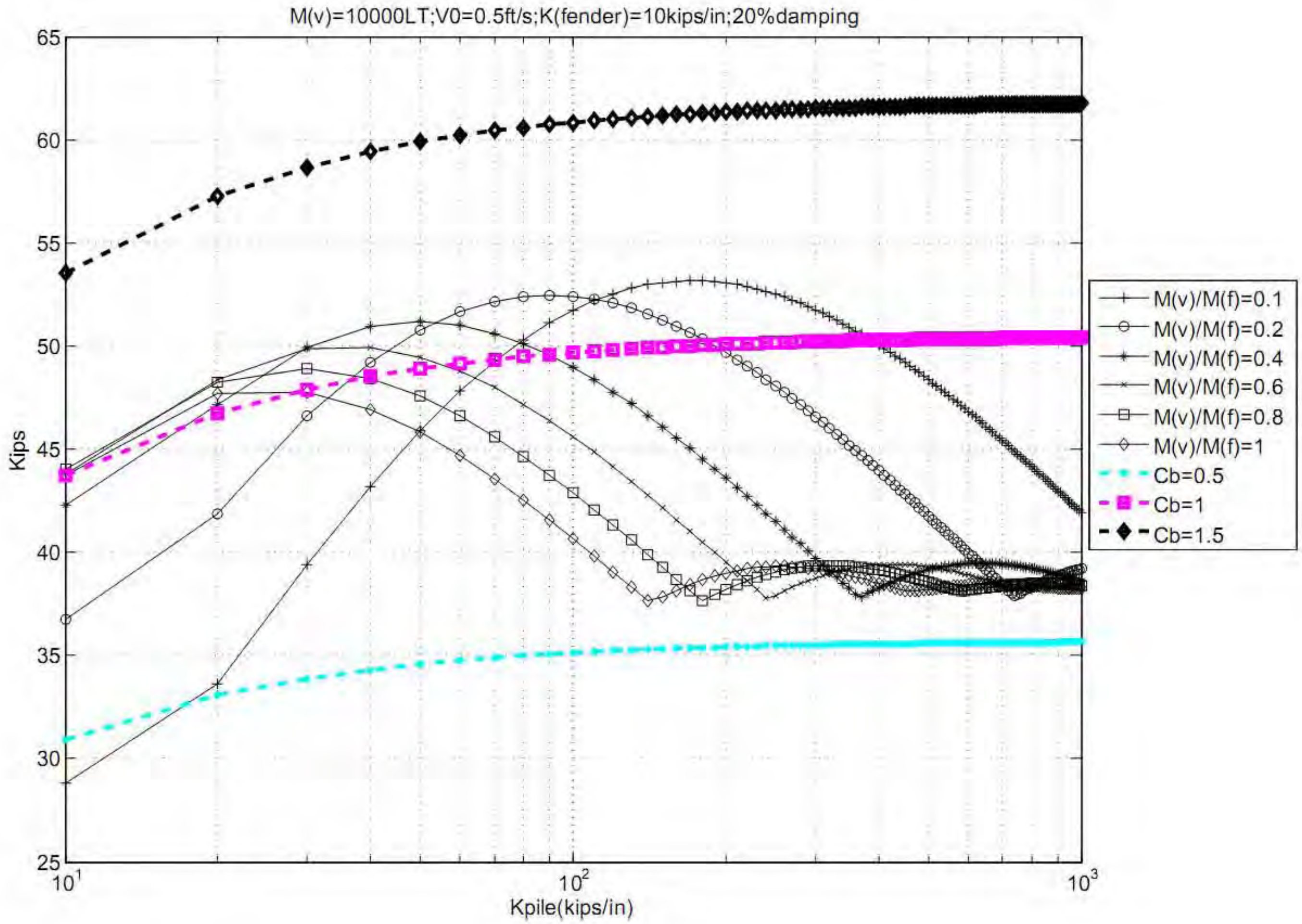
M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.121 Displacement of the Piling System 1D-31a



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.122 Displacement of the Piling System 1D-31b



M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
65
60
55
50
45
40
35
30
25
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.123 Reaction Force of the Piling System 1D-31a

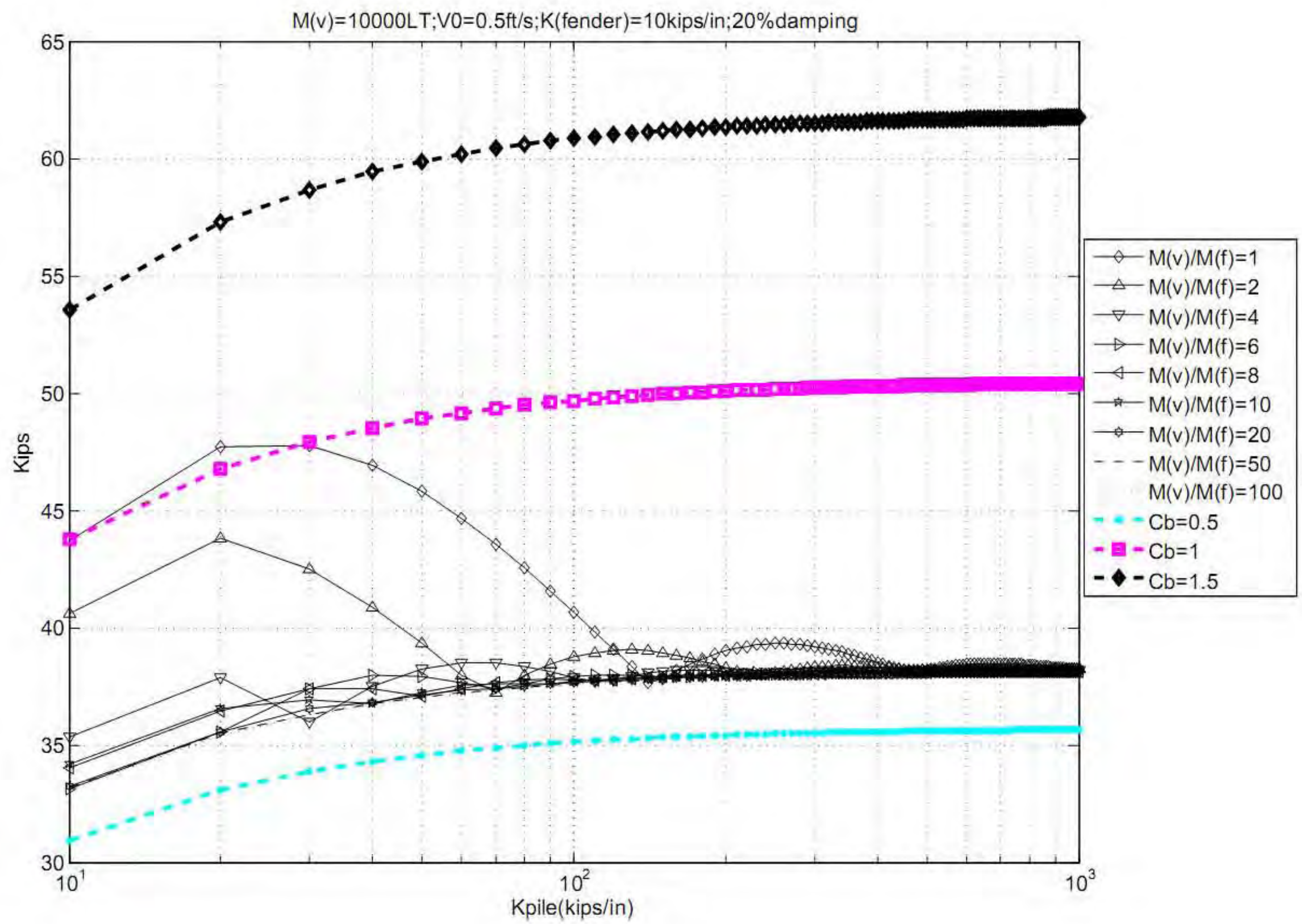

M(v)=10000LT;V0=0.5ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.124 Reaction Force of the Piling System 1D-31b

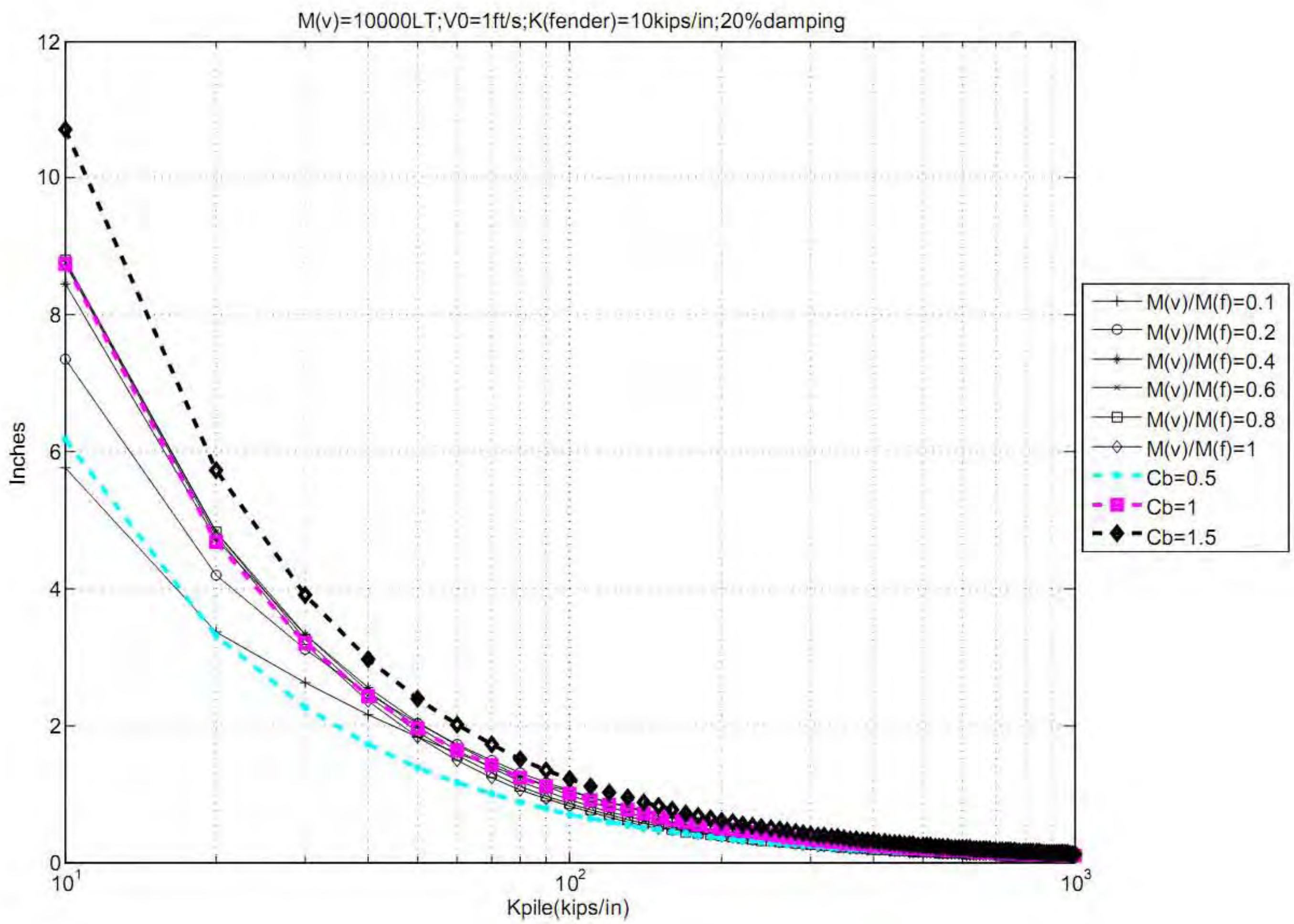
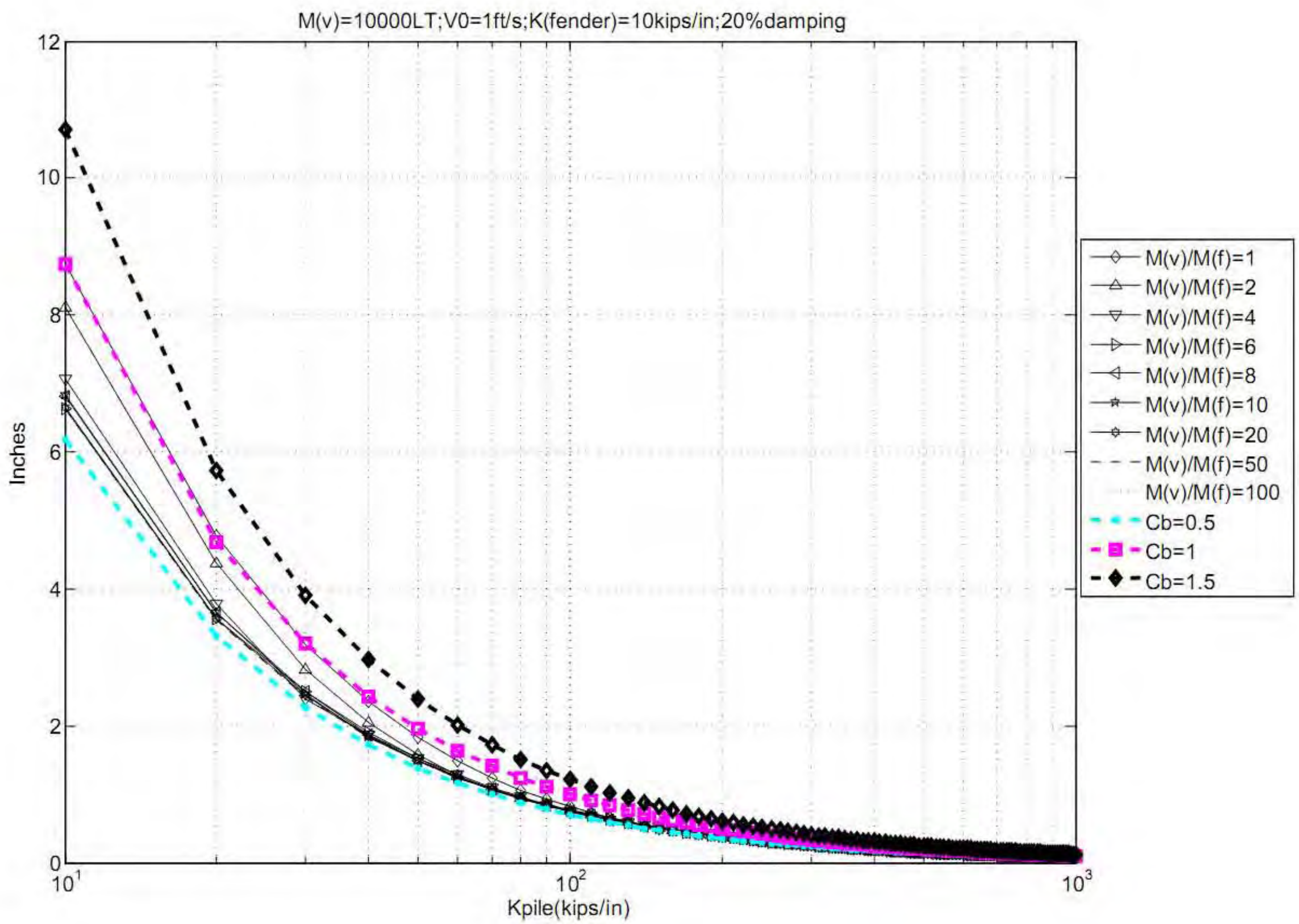
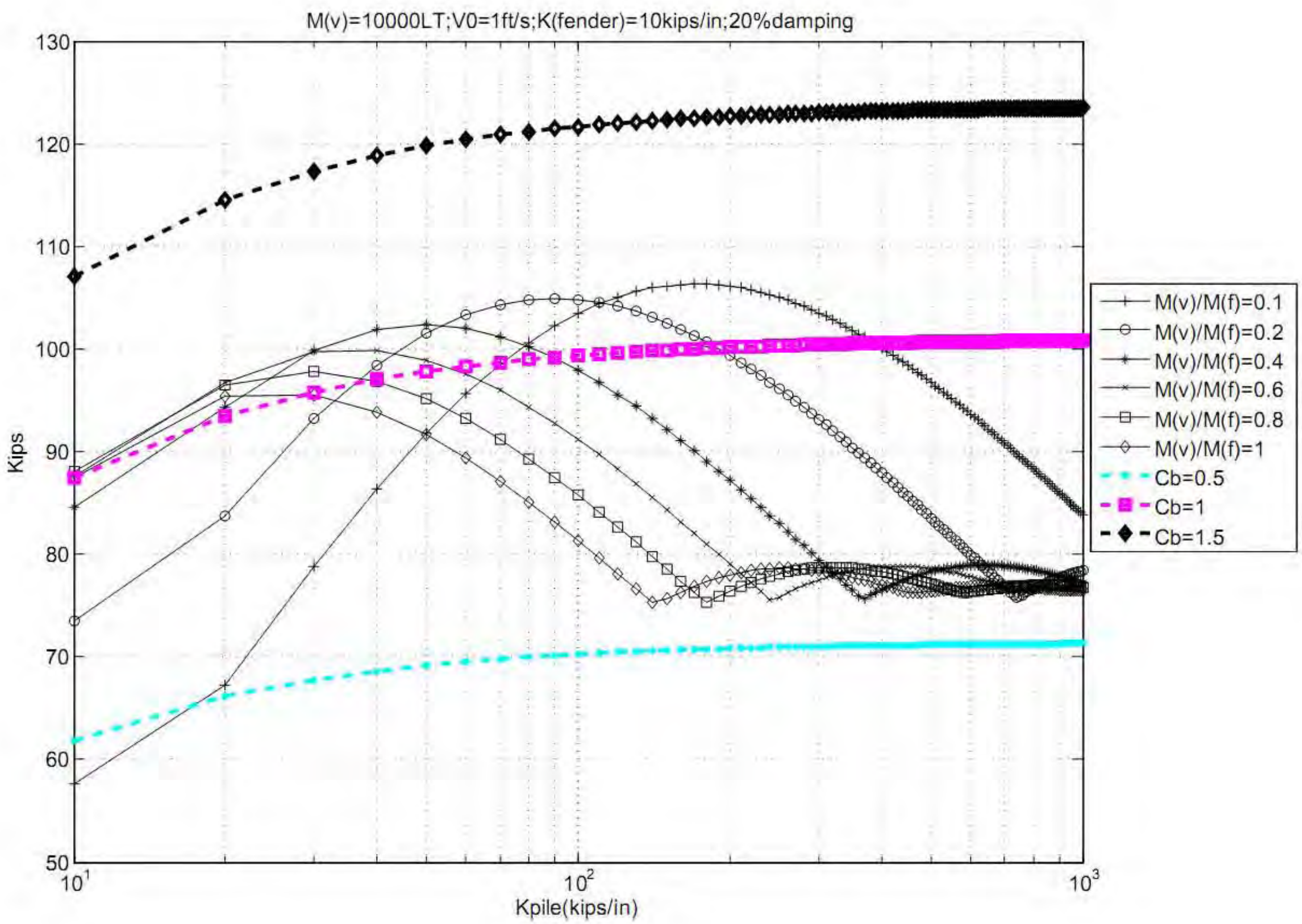

M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5
0
2
4
6
8
10
12
10^1
10^2
10^3

Fig. A.125 Displacement of the Piling System 1D-32a



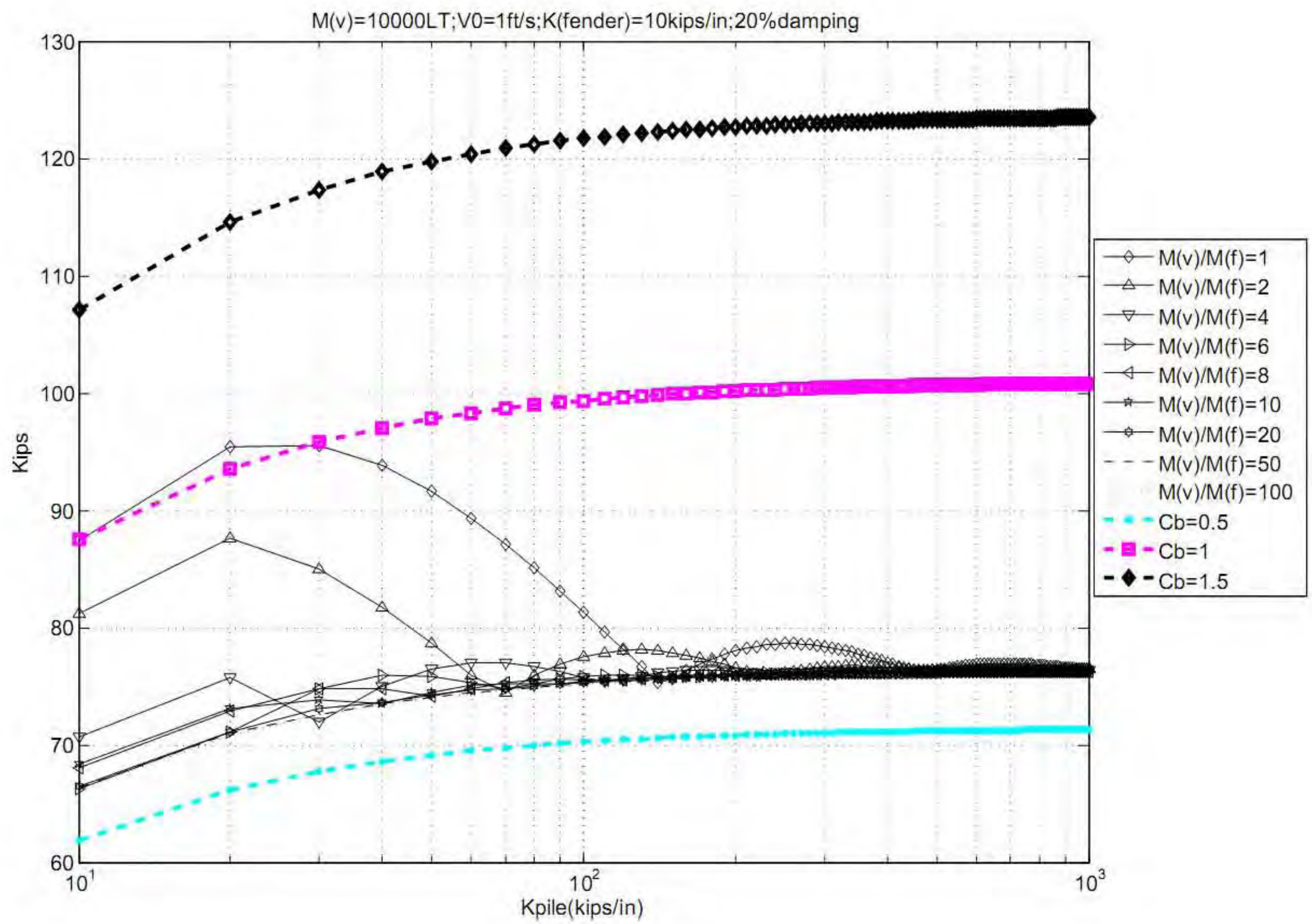
M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Inches
Kpile(kips/in)
0
2
4
6
8
10
12
10^1
10^2
10^3
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.126 Displacement of the Piling System 1D-32b



M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
Kpile(kips/in)
130
120
110
100
90
80
70
60
50
10^1
10^2
10^3
M(v)/M(f)=0.1
M(v)/M(f)=0.2
M(v)/M(f)=0.4
M(v)/M(f)=0.6
M(v)/M(f)=0.8
M(v)/M(f)=1
Cb=0.5
Cb=1
Cb=1.5

Fig. A.127 Reaction Force of the Piling System 1D-32a



M(v)=10000LT;V0=1ft/s;K(fender)=10kips/in;20%damping
Kips
130
120
110
100
90
80
70
60
10^1
10^2
10^3
Kpile(kips/in)
M(v)/M(f)=1
M(v)/M(f)=2
M(v)/M(f)=4
M(v)/M(f)=6
M(v)/M(f)=8
M(v)/M(f)=10
M(v)/M(f)=20
M(v)/M(f)=50
M(v)/M(f)=100
Cb=0.5
Cb=1
Cb=1.5

Fig. A.128 Reaction Force of the Piling System 1D-32b

Annex C

2-DOF Response Plots

Annex C

Results for Two Dimensional Analysis

The responses of the piling system in two-dimensional analysis are numerically calculated given the mass of the vessel and the float, the stiffness of the fender and the stiffness of the piling system fixed on the float. In the analysis, the ratio of the mass of the vessel to the float is chosen from 0.1 to 100. The mass of the vessel varies from 800LT to 10,000LT for a certain mass ratio. The stiffness of the fender is chosen as 10kips/in, the stiffness of a single pile ranges from 10kips/in to 1000kips/in, therefore the stiffness of the piling system that consists of three piles ranges from 30kips/in to 3000kips/in. In the diagrams given below, the x-axis is chosen as the stiffness of each single pile of the piling system, and the responses on the y-axis are chosen as the maximum responses among all three piles. The damping ratios are chosen from 2% to 20% of critical damping.

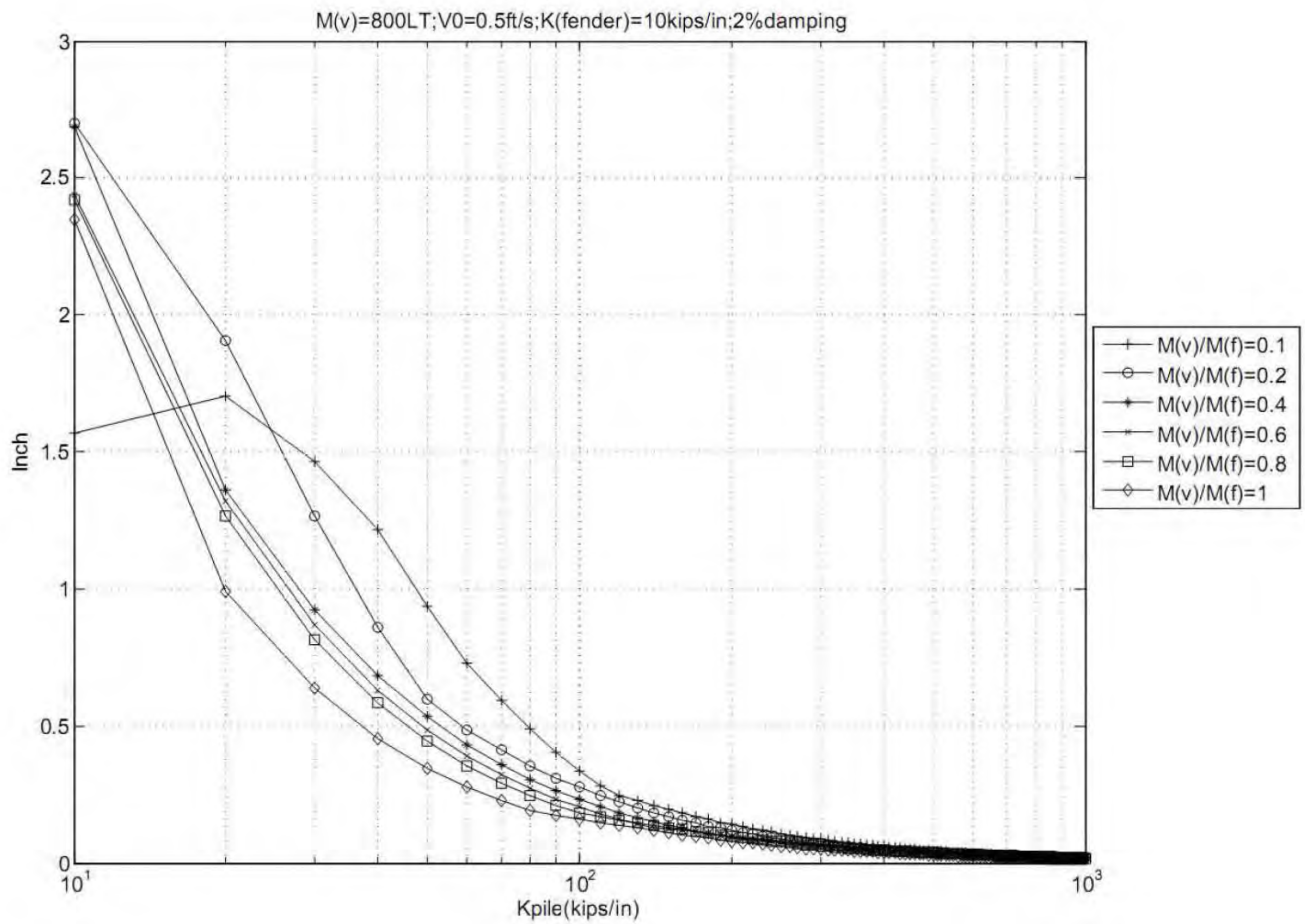


Fig. A.129 Displacement of the Piling System 2D-1a

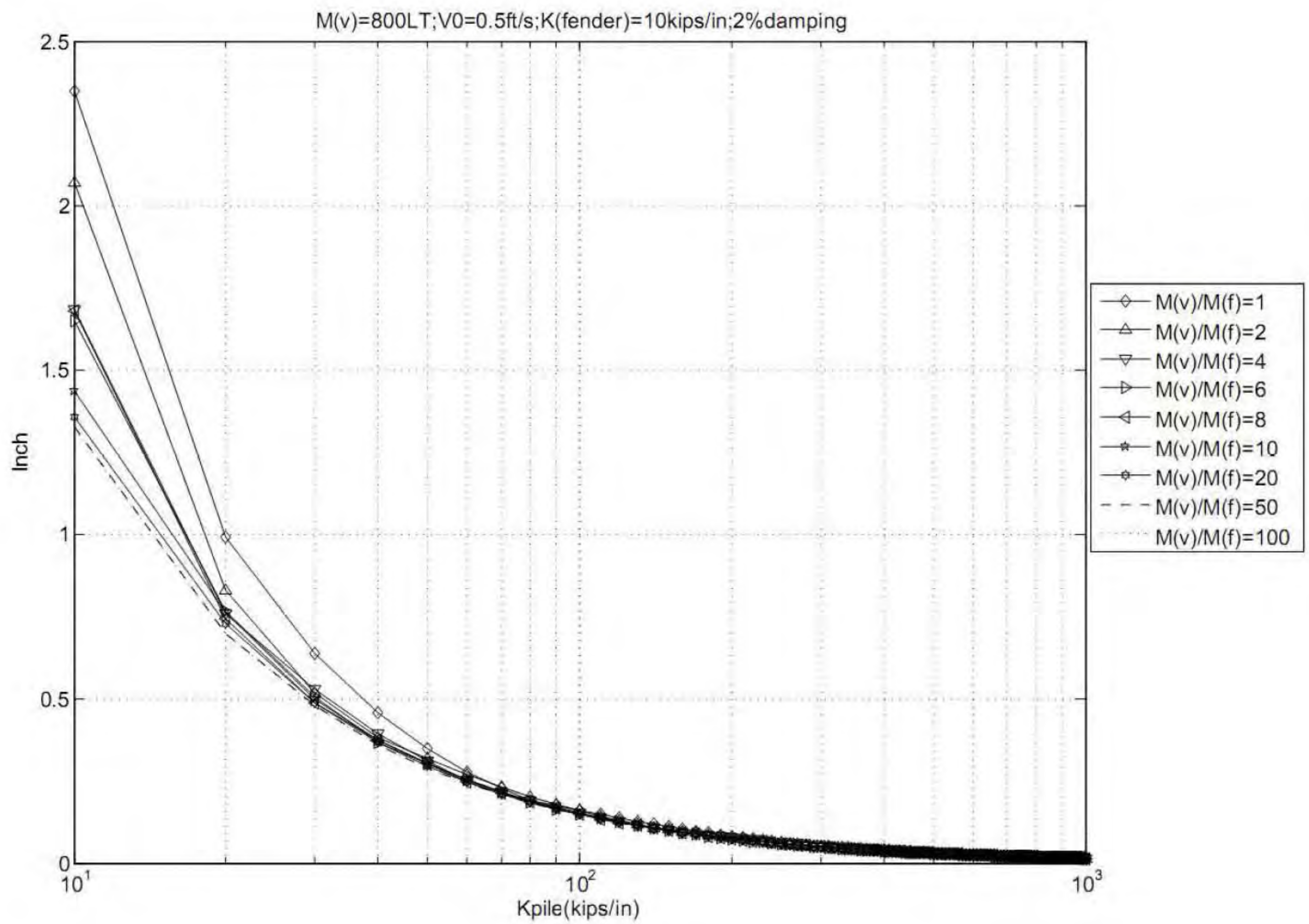


Fig. A.130 Displacement of the Piling System 2D-1b

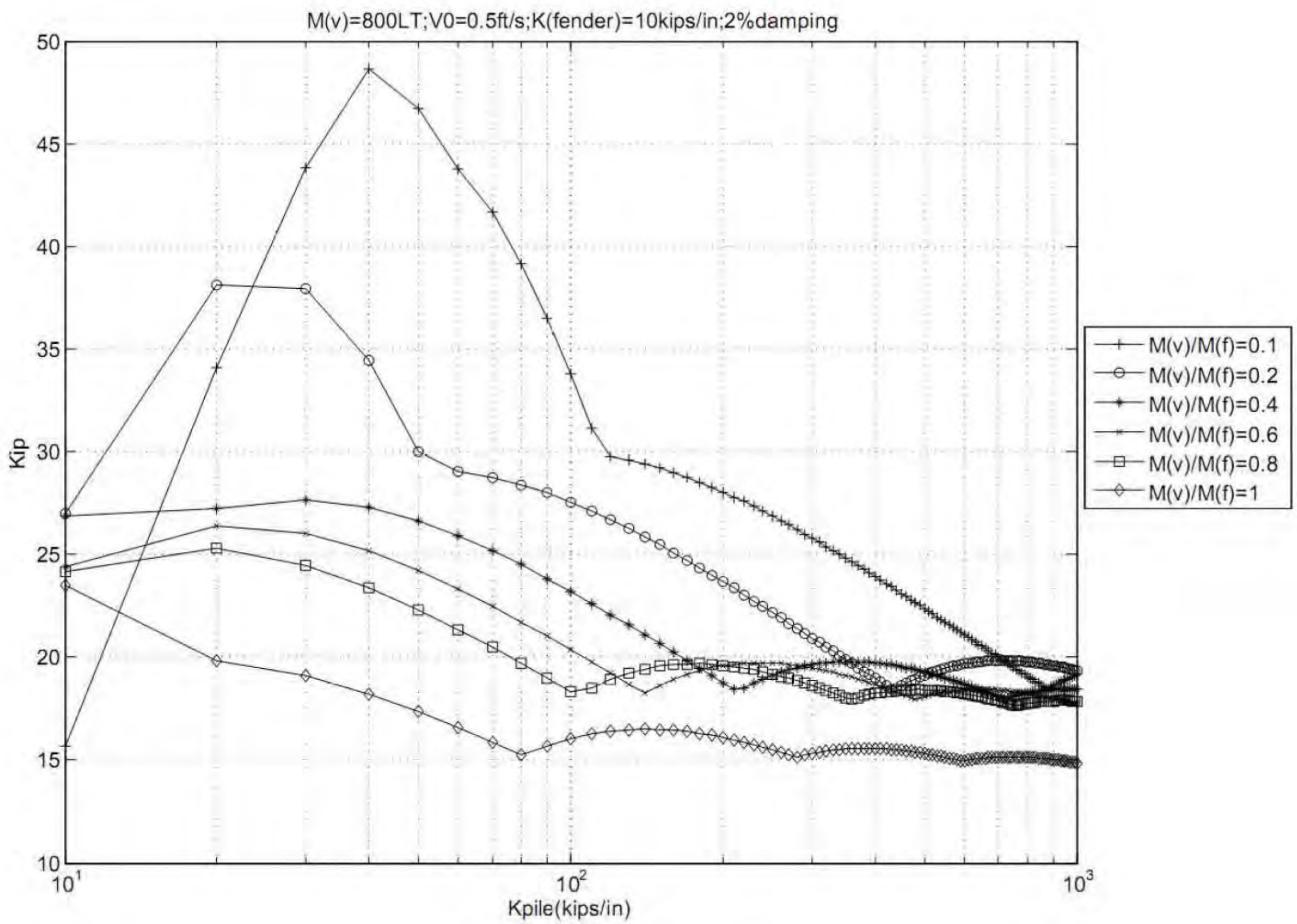


Fig. A.131 Reaction Force of the Piling System 2D-1a

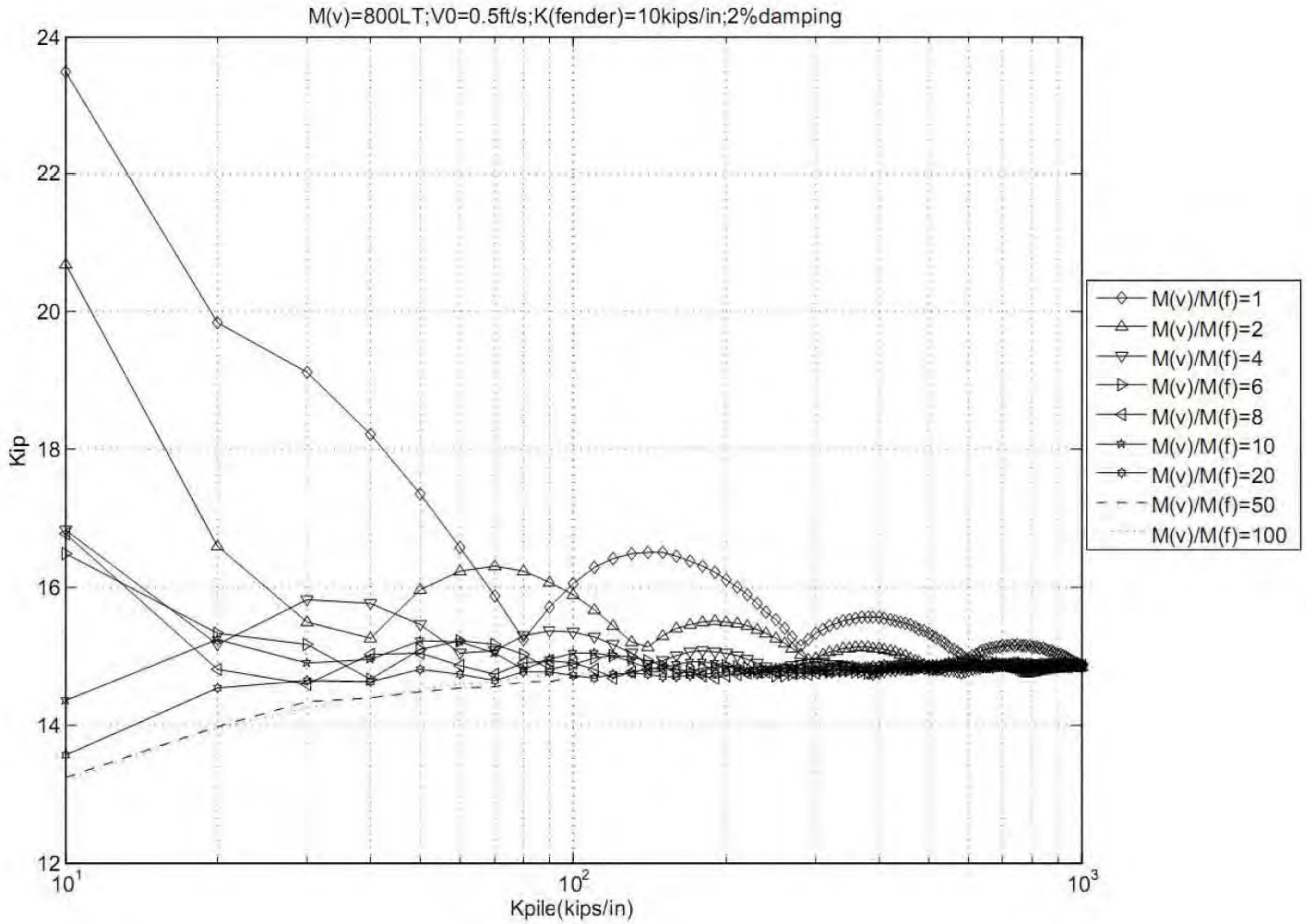


Fig. A.132 Reaction Force of the Piling System 2D-1b

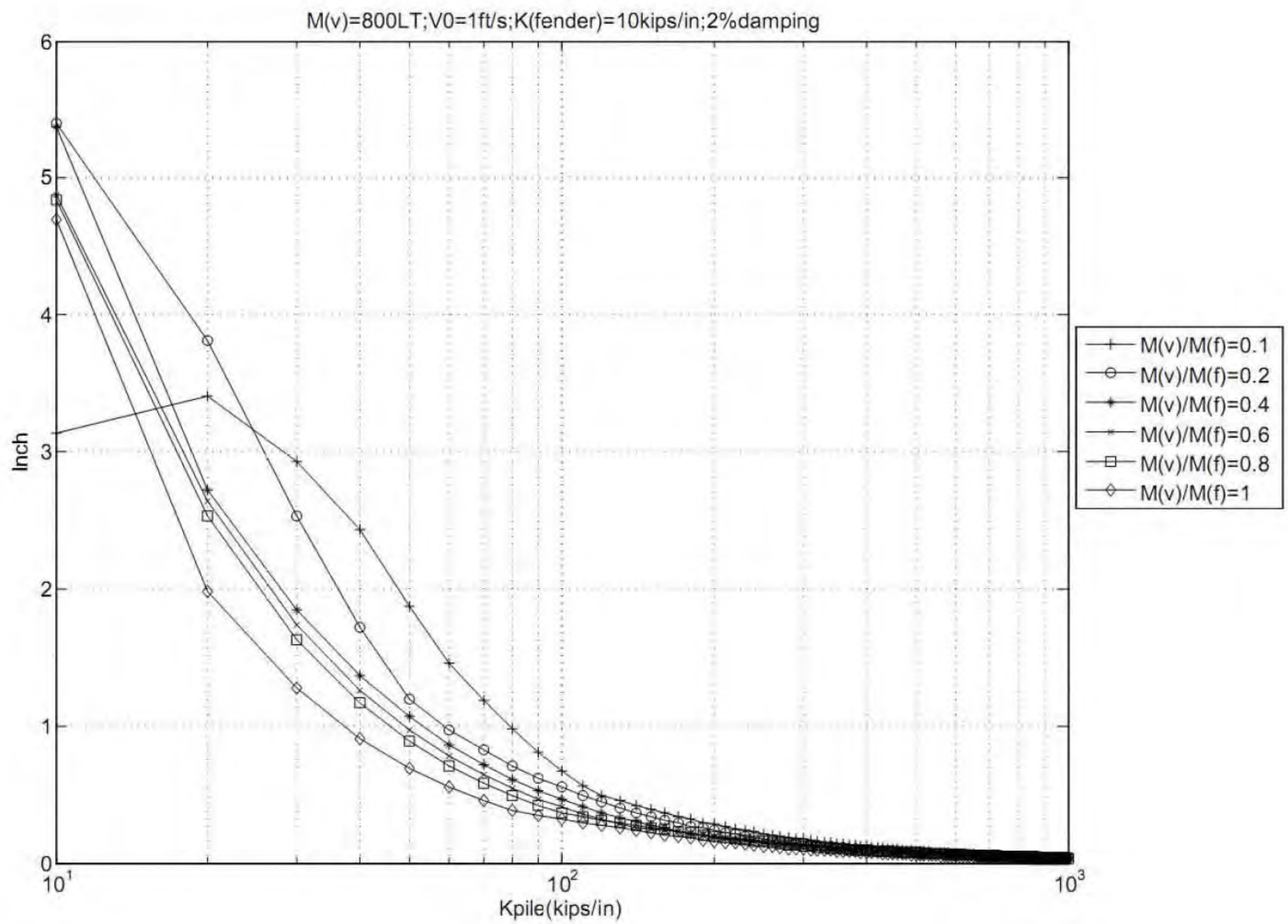


Fig. A.133 Displacement of the Piling System 2D-2a

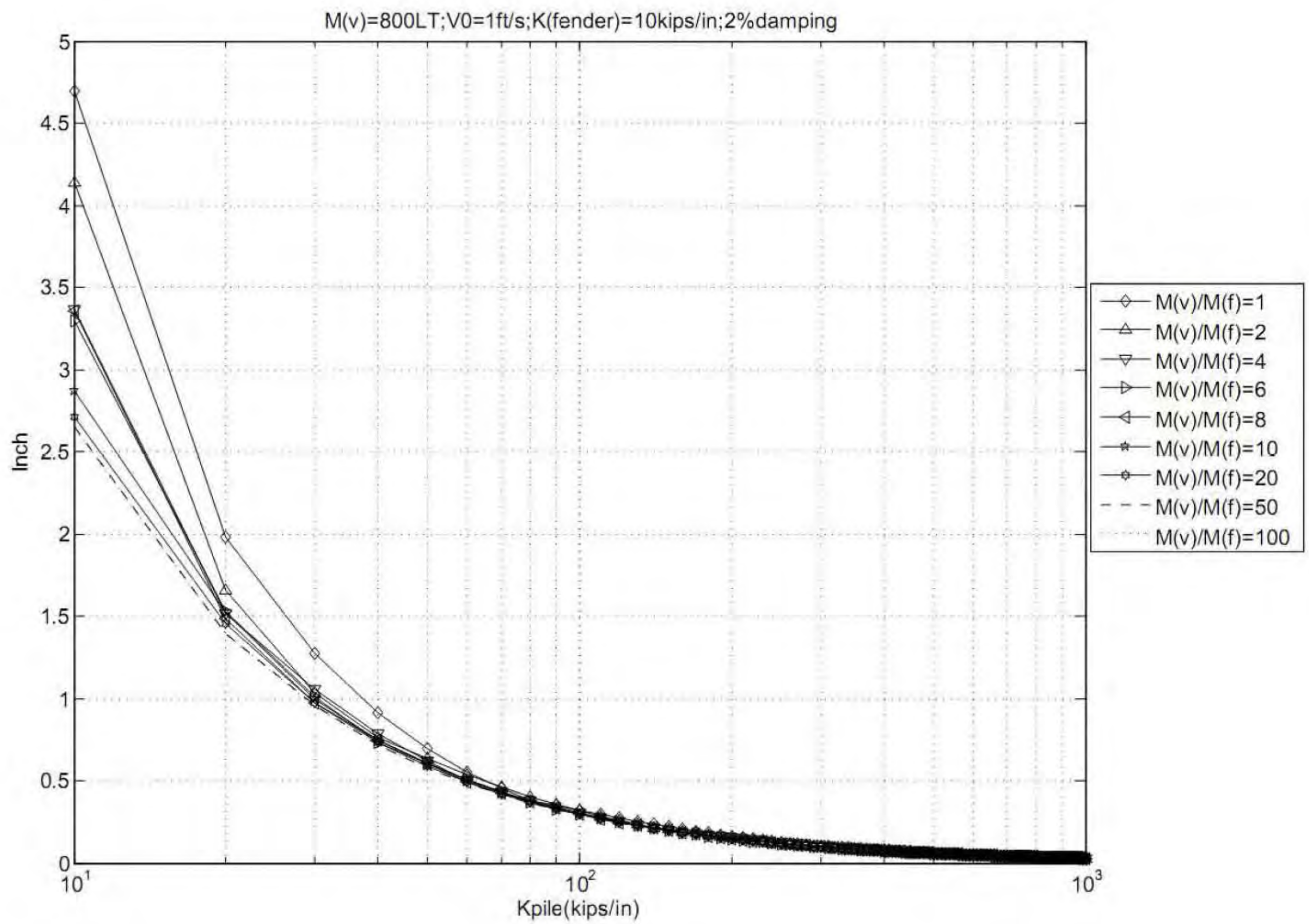


Fig. A.134 Displacement of the Piling System 2D-2b

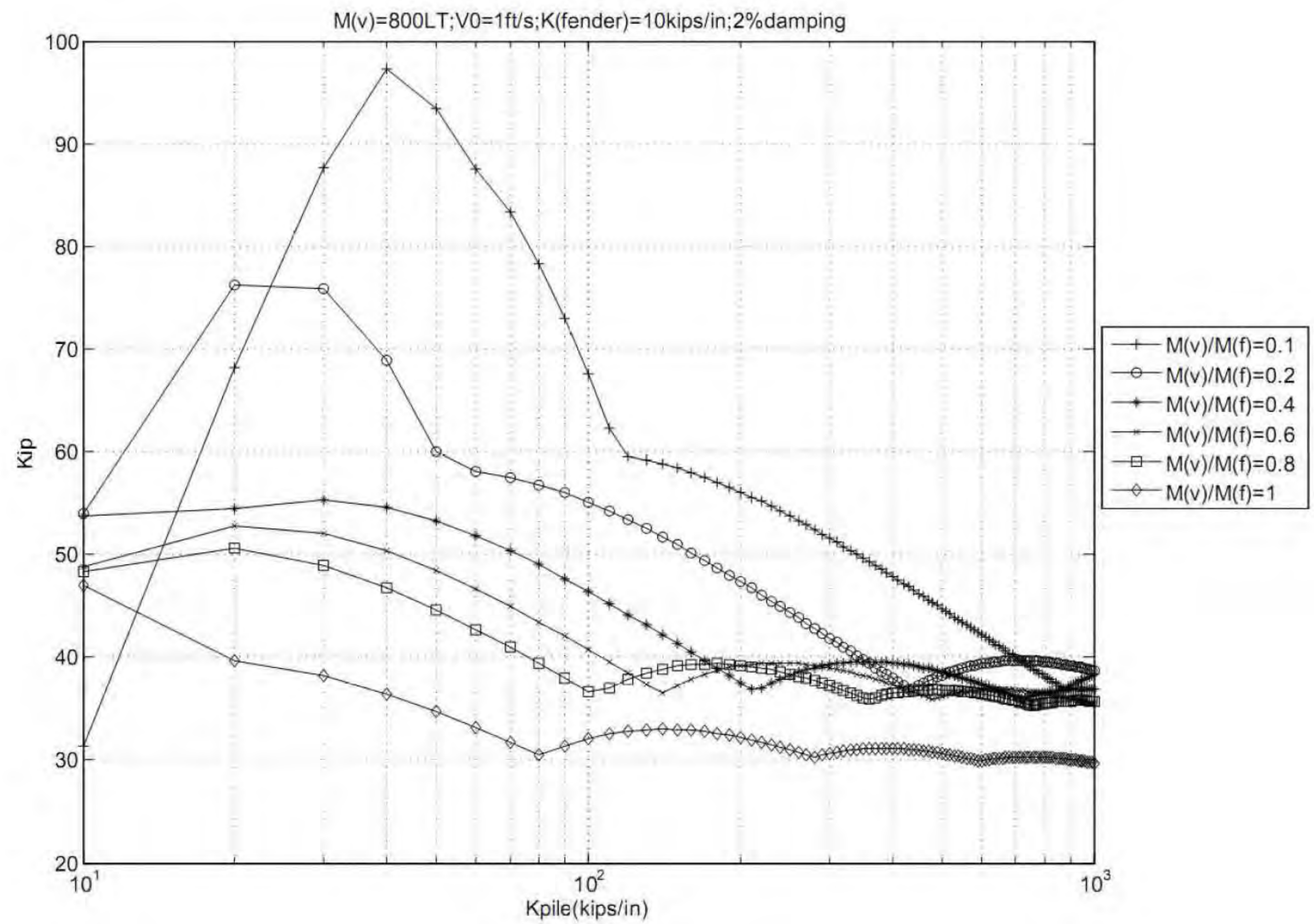


Fig. A.135 Reaction Force of the Piling System 2D-2a

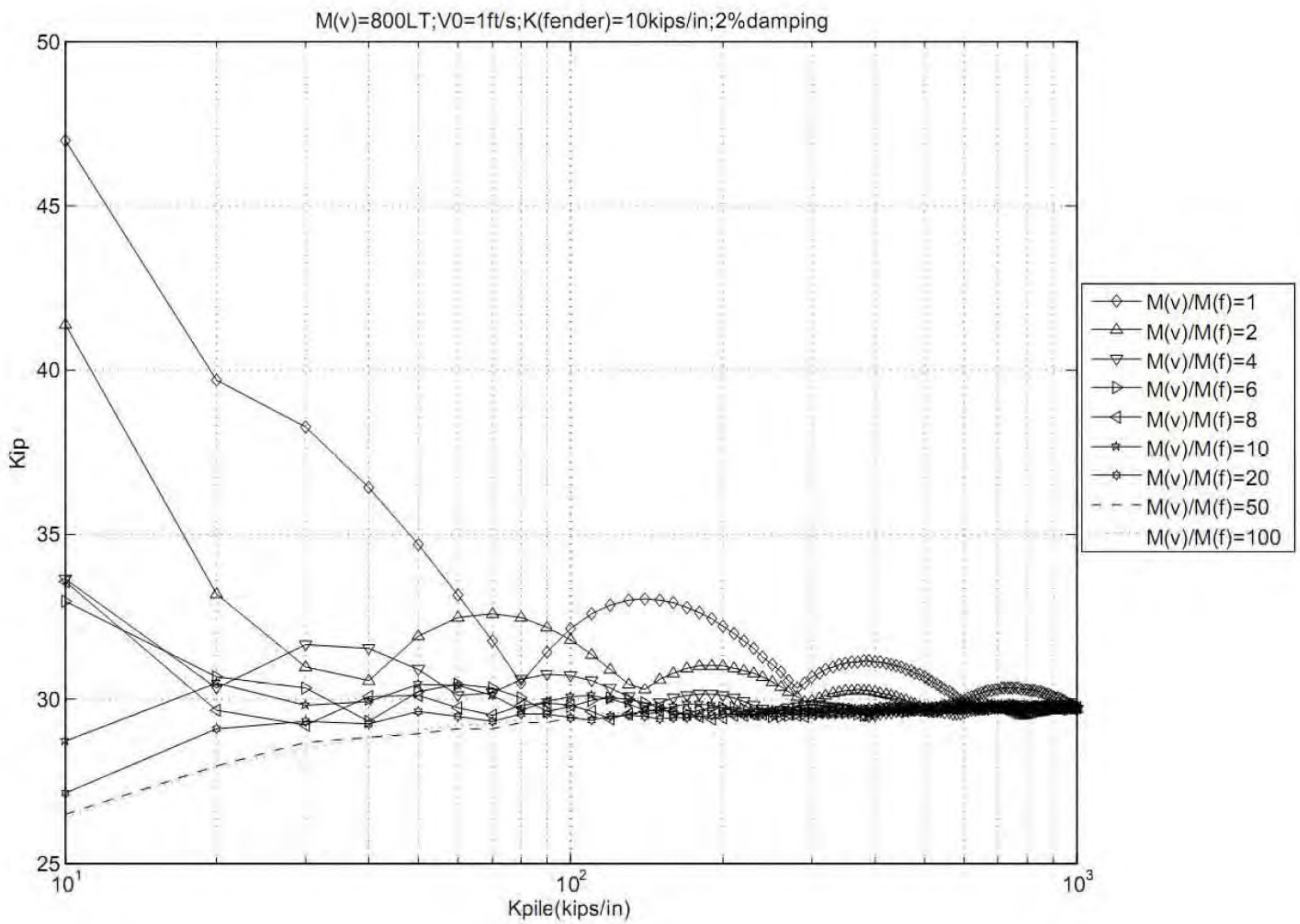


Fig. A.136 Reaction Force of the Piling System 2D-2b

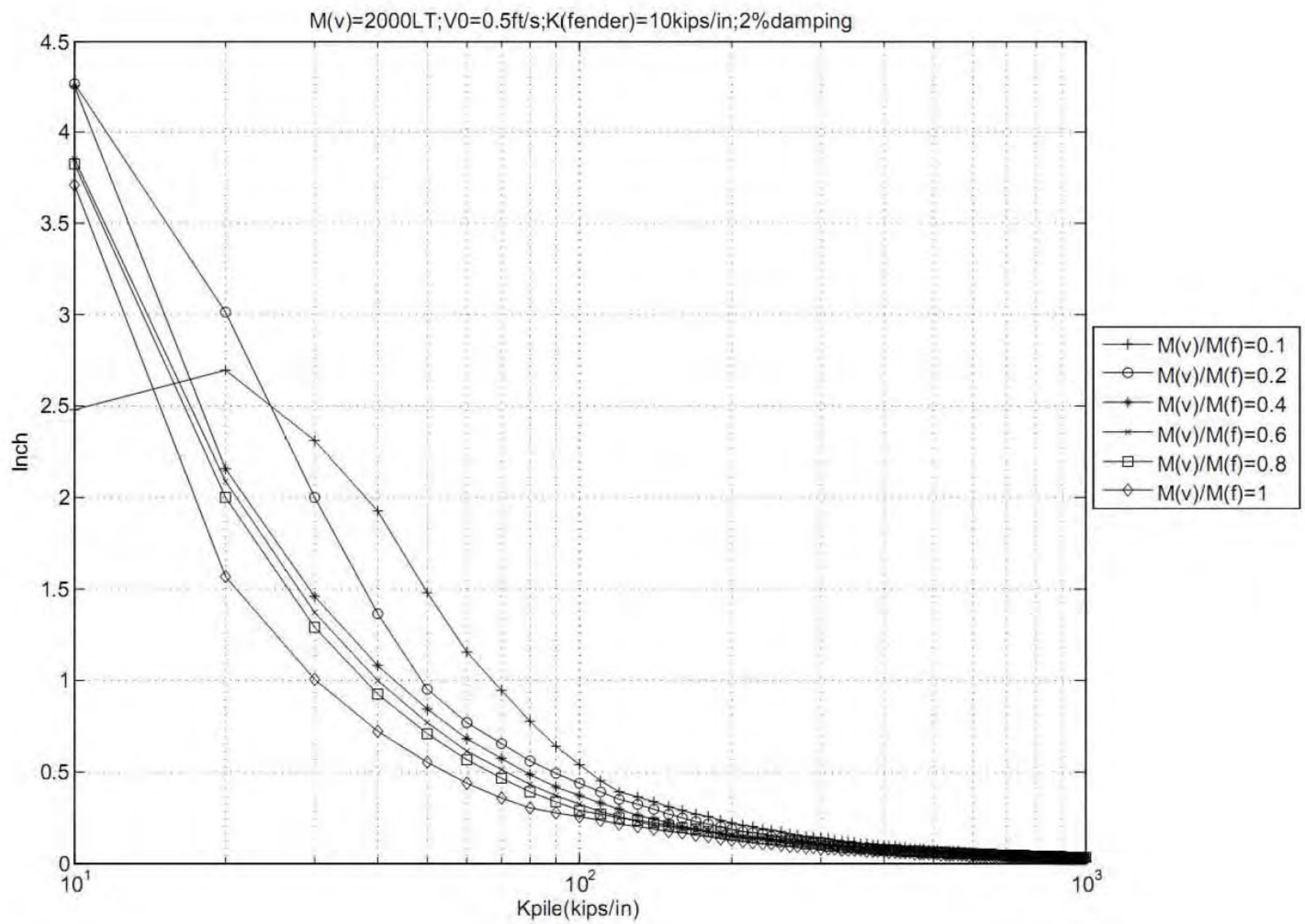


Fig. A.137 Displacement of the Piling System 2D-3a

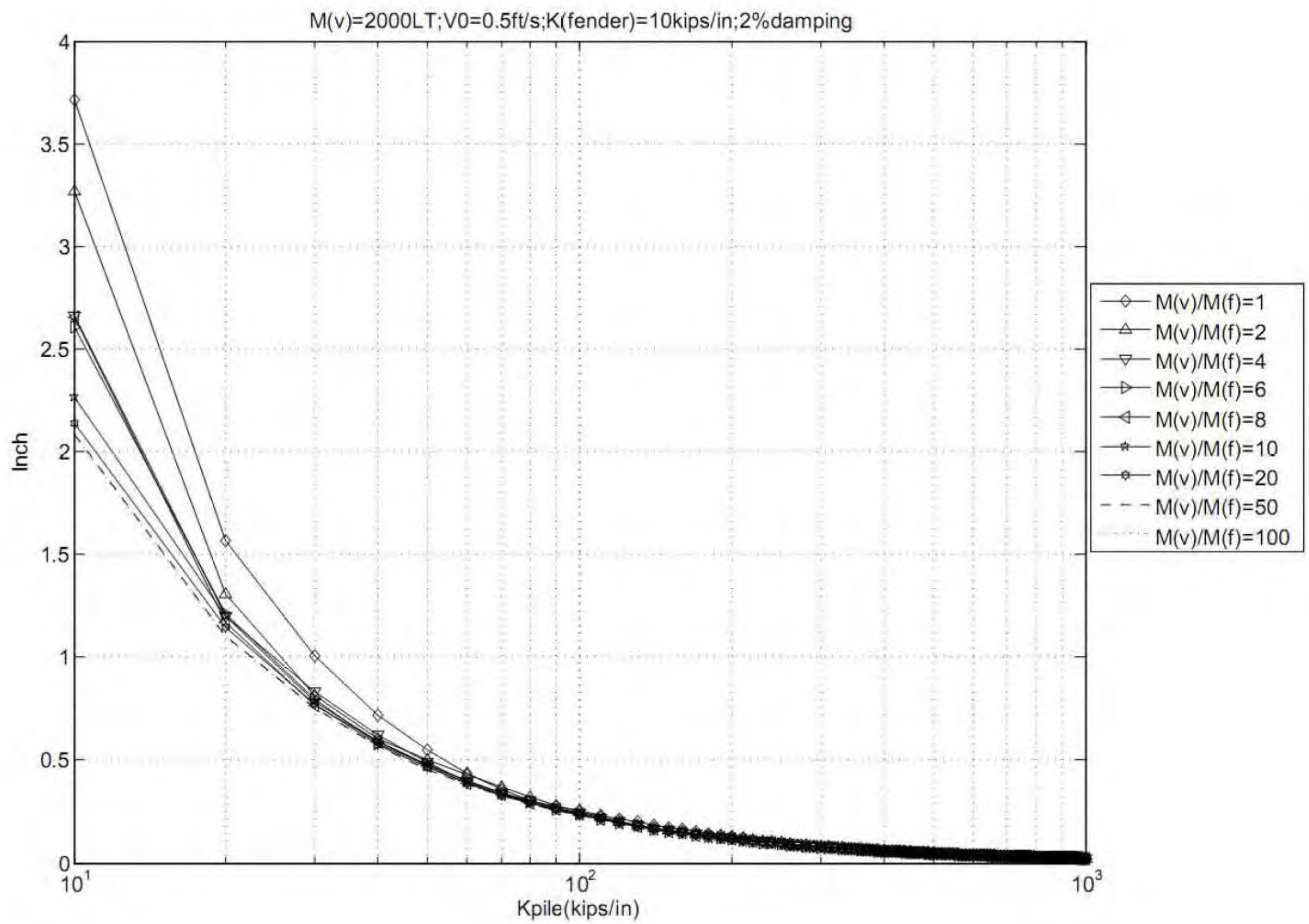


Fig. A.138 Displacement of the Piling System 2D-3b

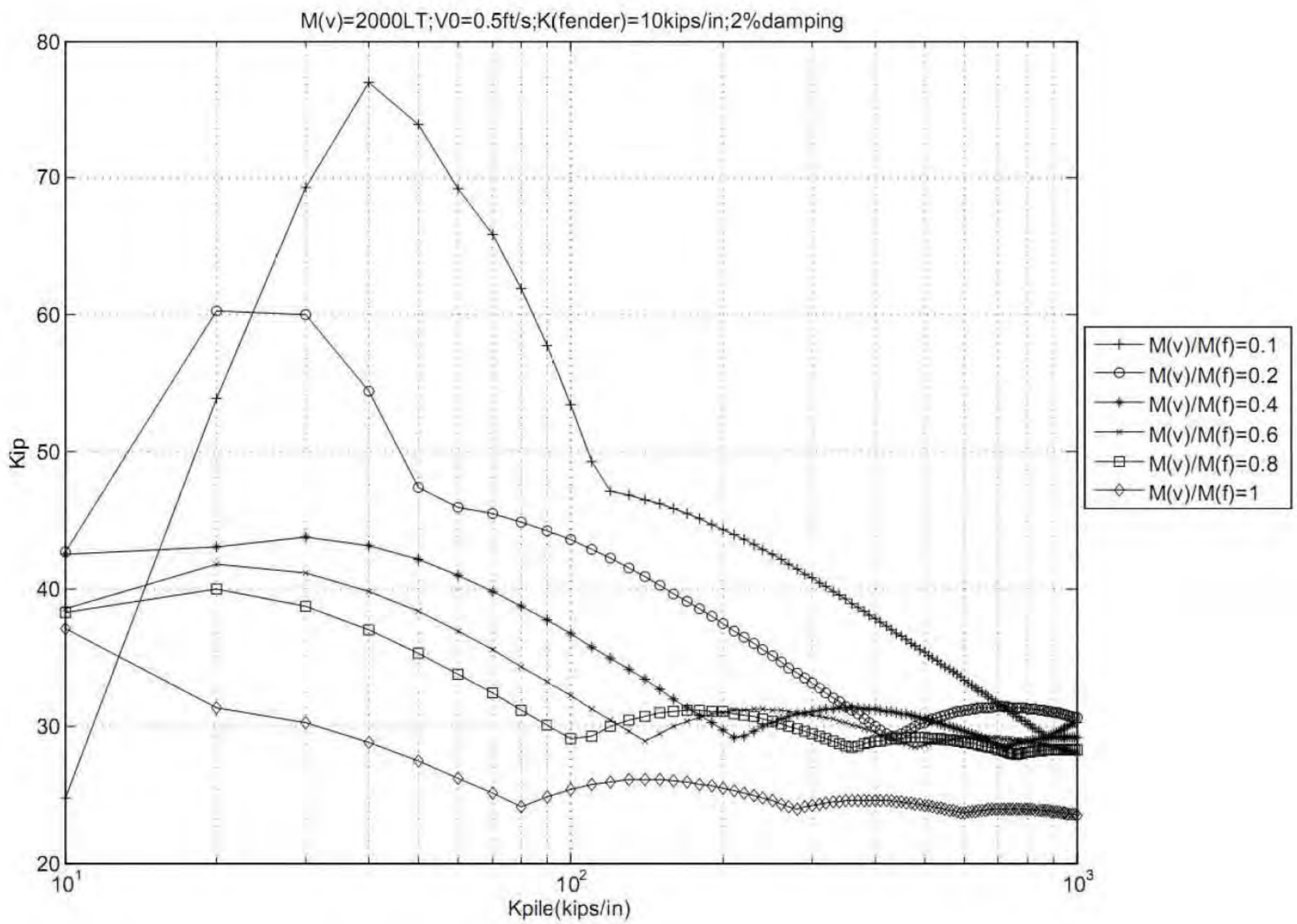


Fig. A.139 Reaction Force of the Piling System 2D-3a

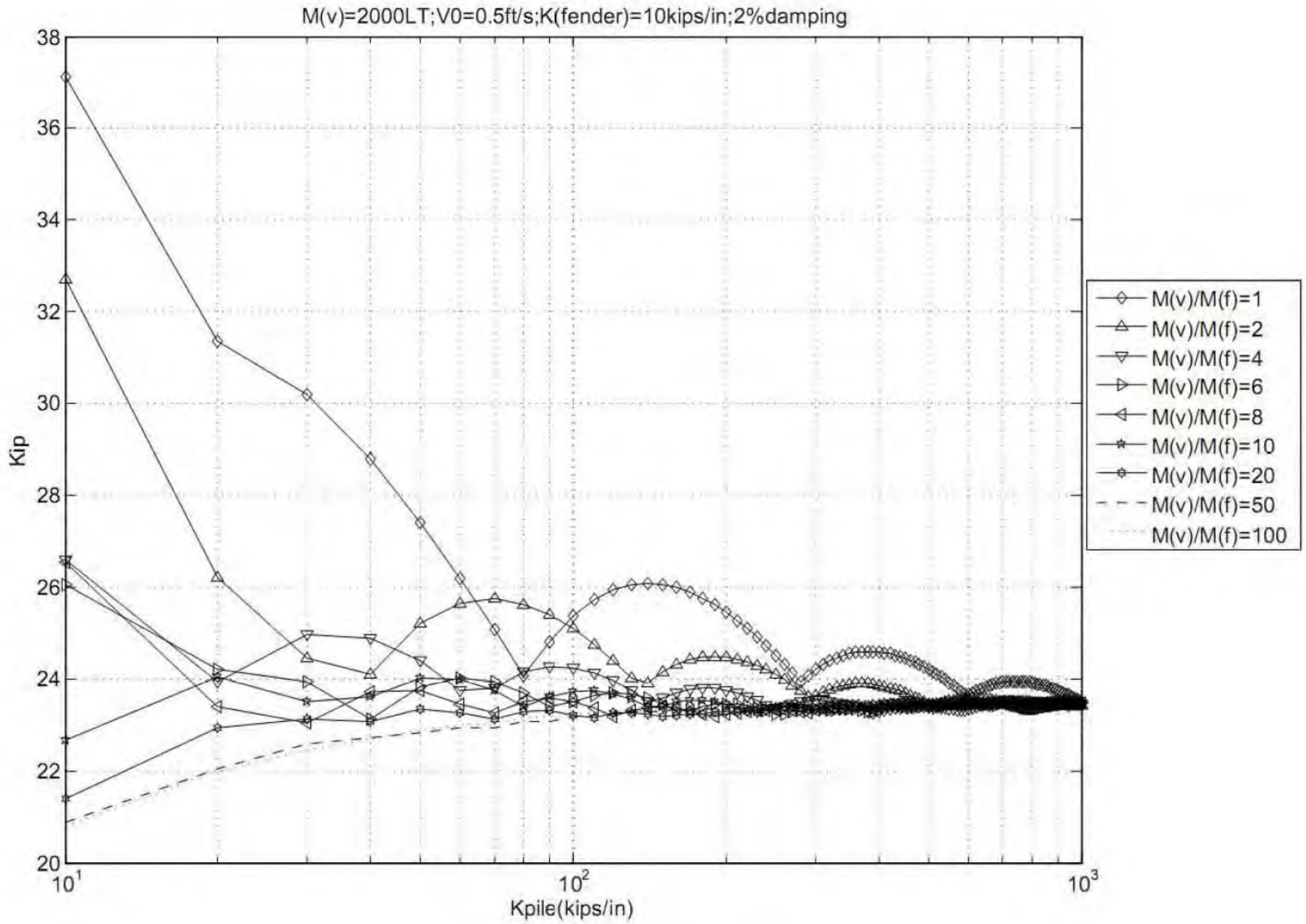


Fig. A.140 Reaction Force of the Piling System 2D-3b

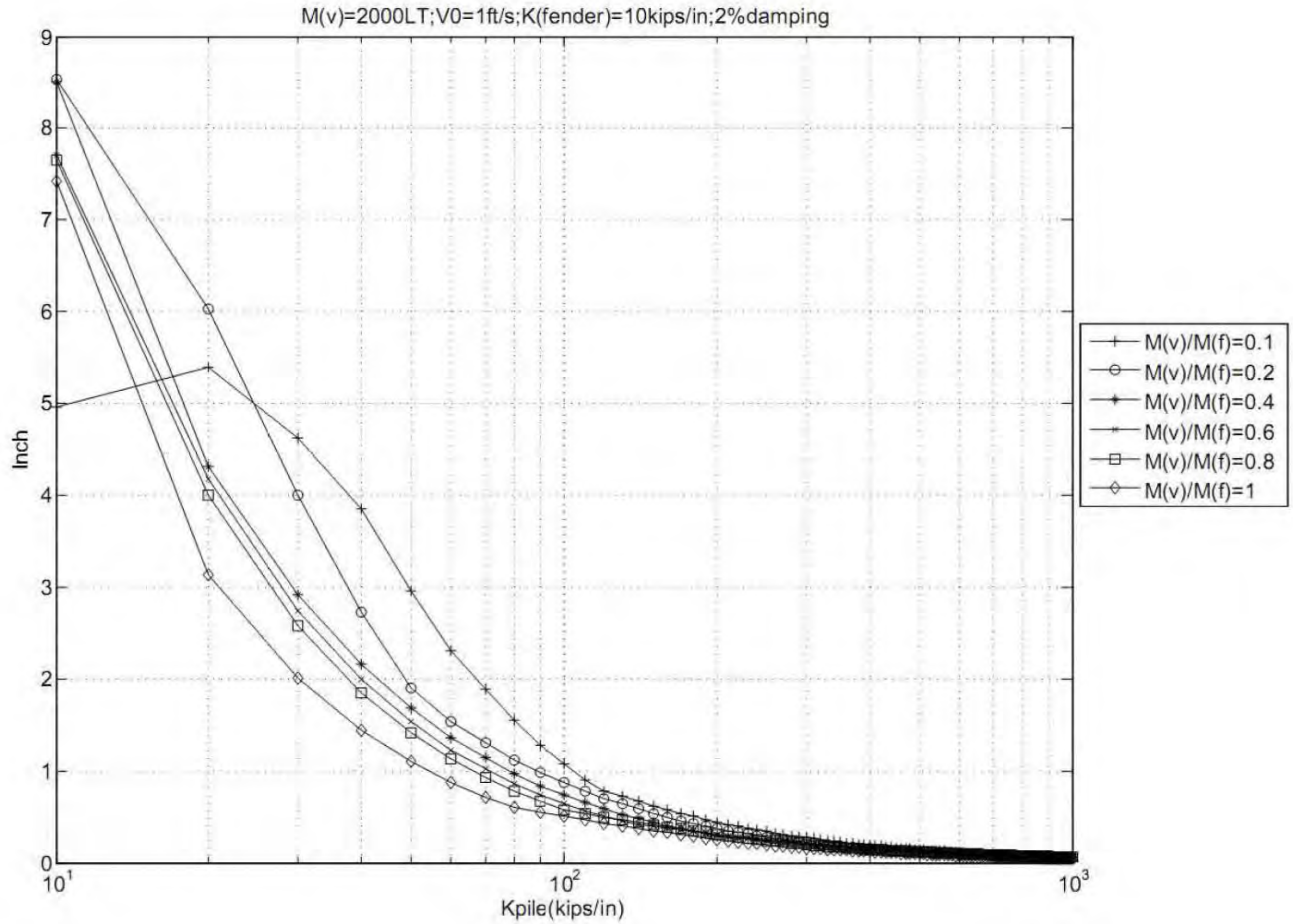


Fig. A.141 Displacement of the Piling System 2D-4a

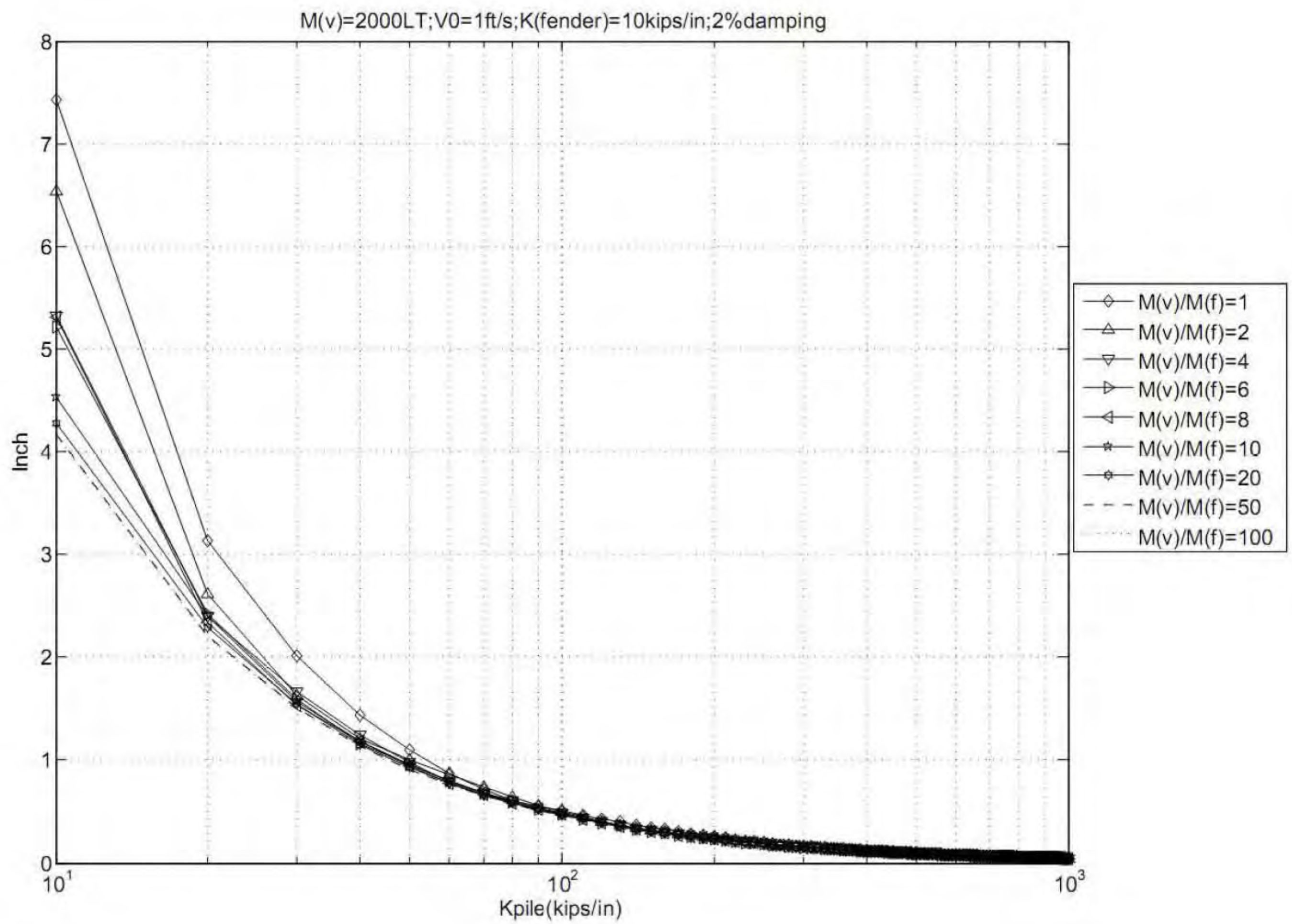


Fig. A.142 Displacement of the Piling System 2D-4b

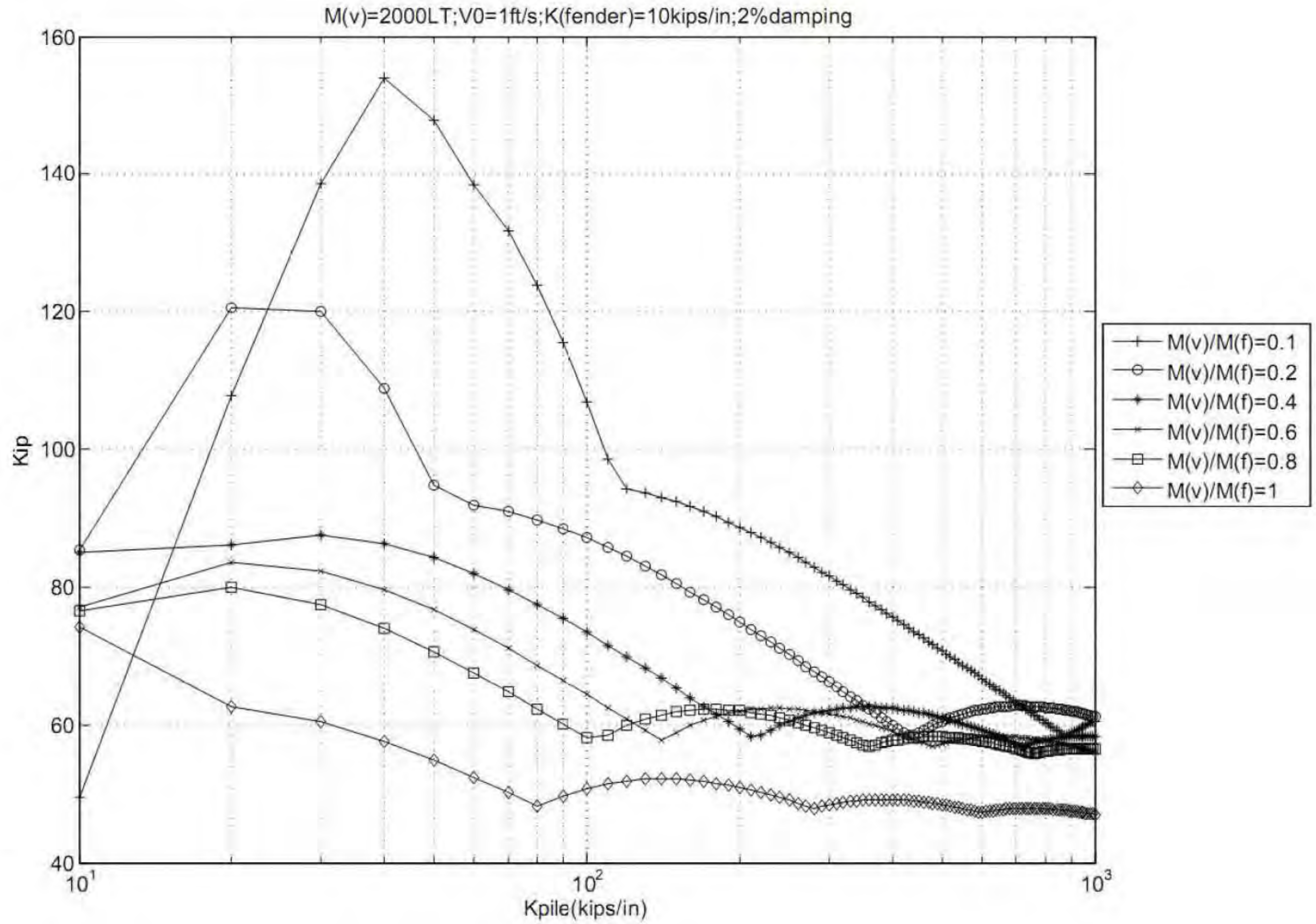


Fig. A.143 Reaction Force of the Piling System 2D-4a

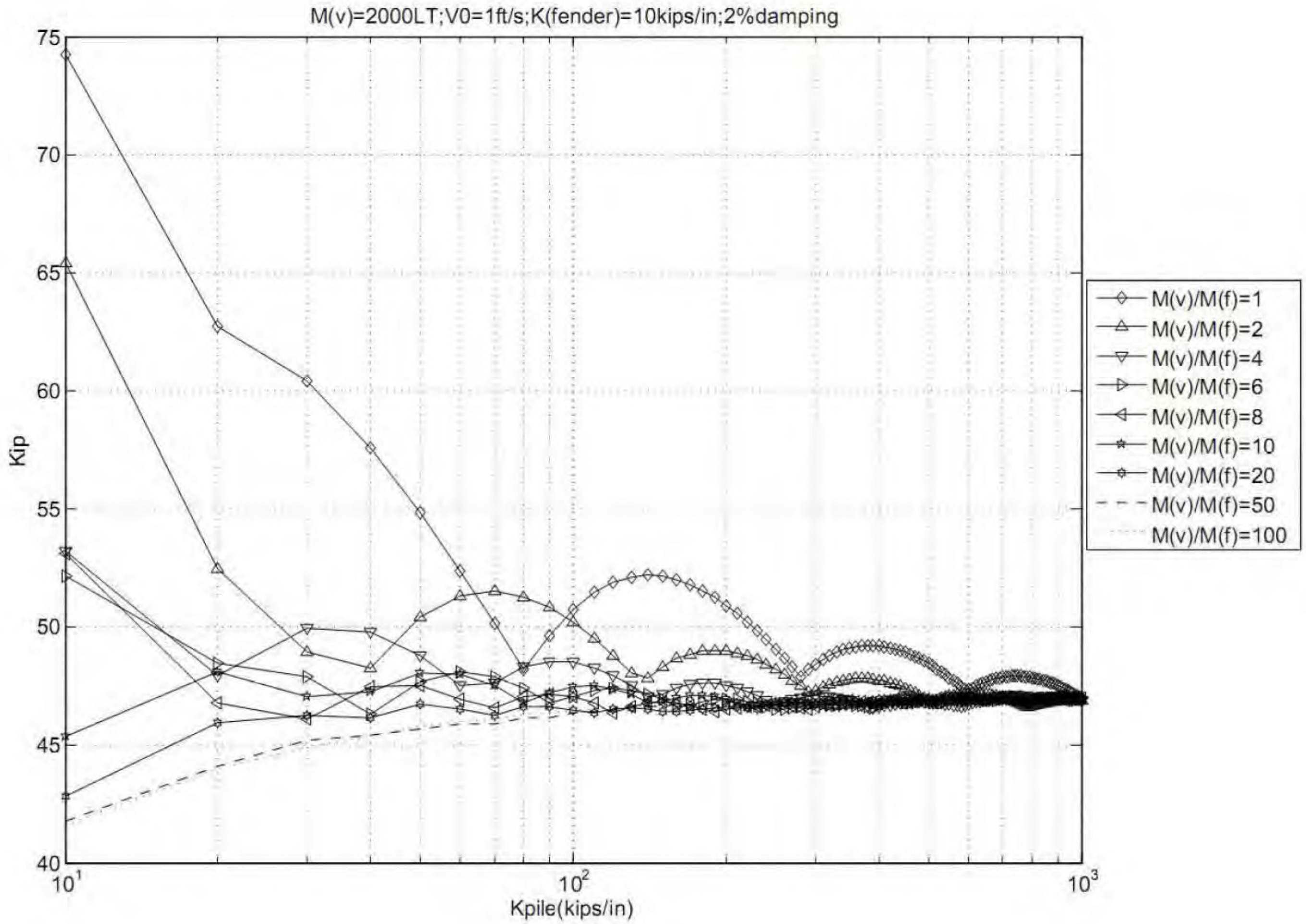


Fig. A.144 Reaction Force of the Piling System 2D-4b

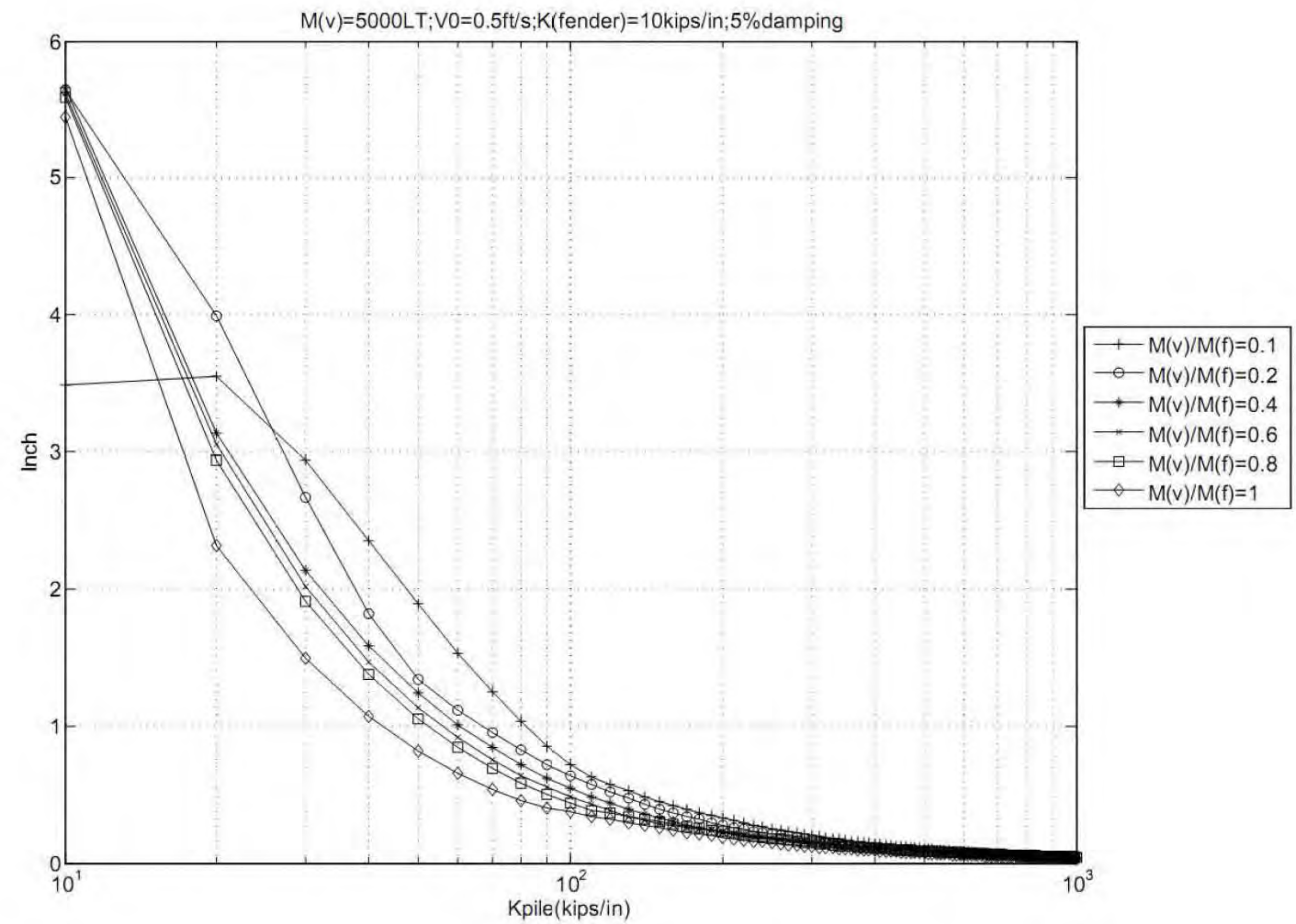


Fig. A.145 Displacement of the Piling System 2D-5a

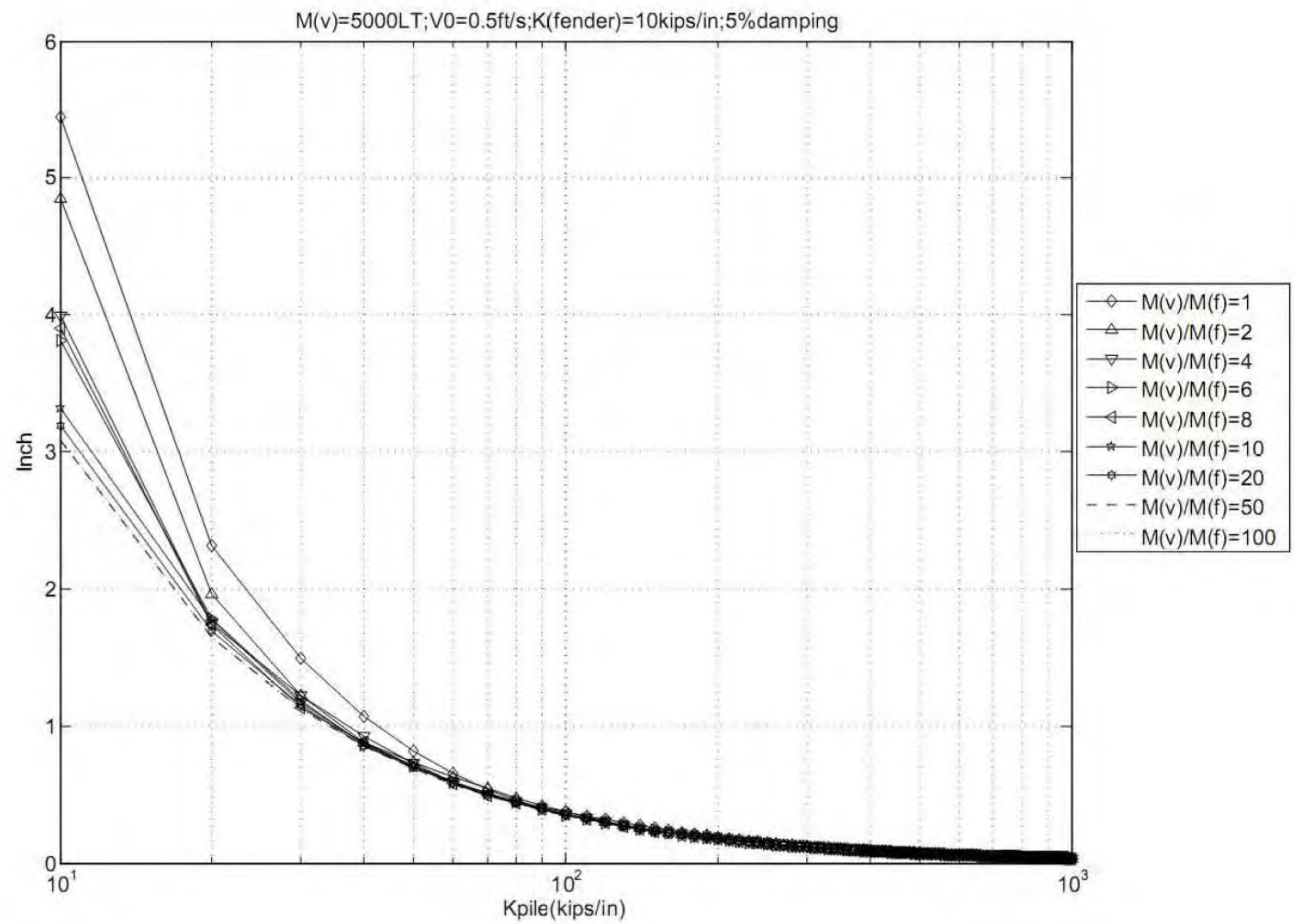


Fig. A.146 Displacement of the Piling System 2D-5b

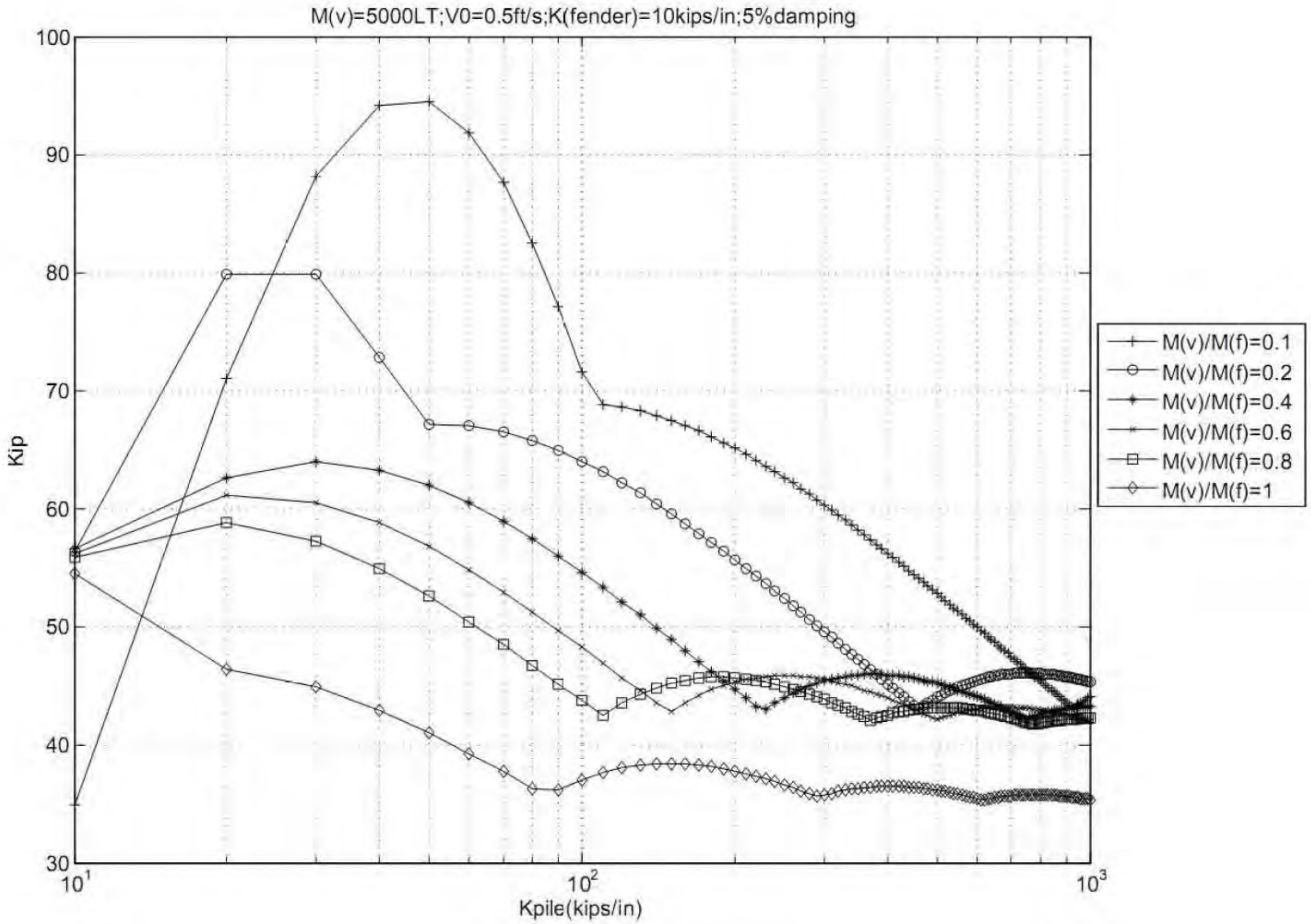


Fig. A.147 Reaction Force of the Piling System 2D-5a

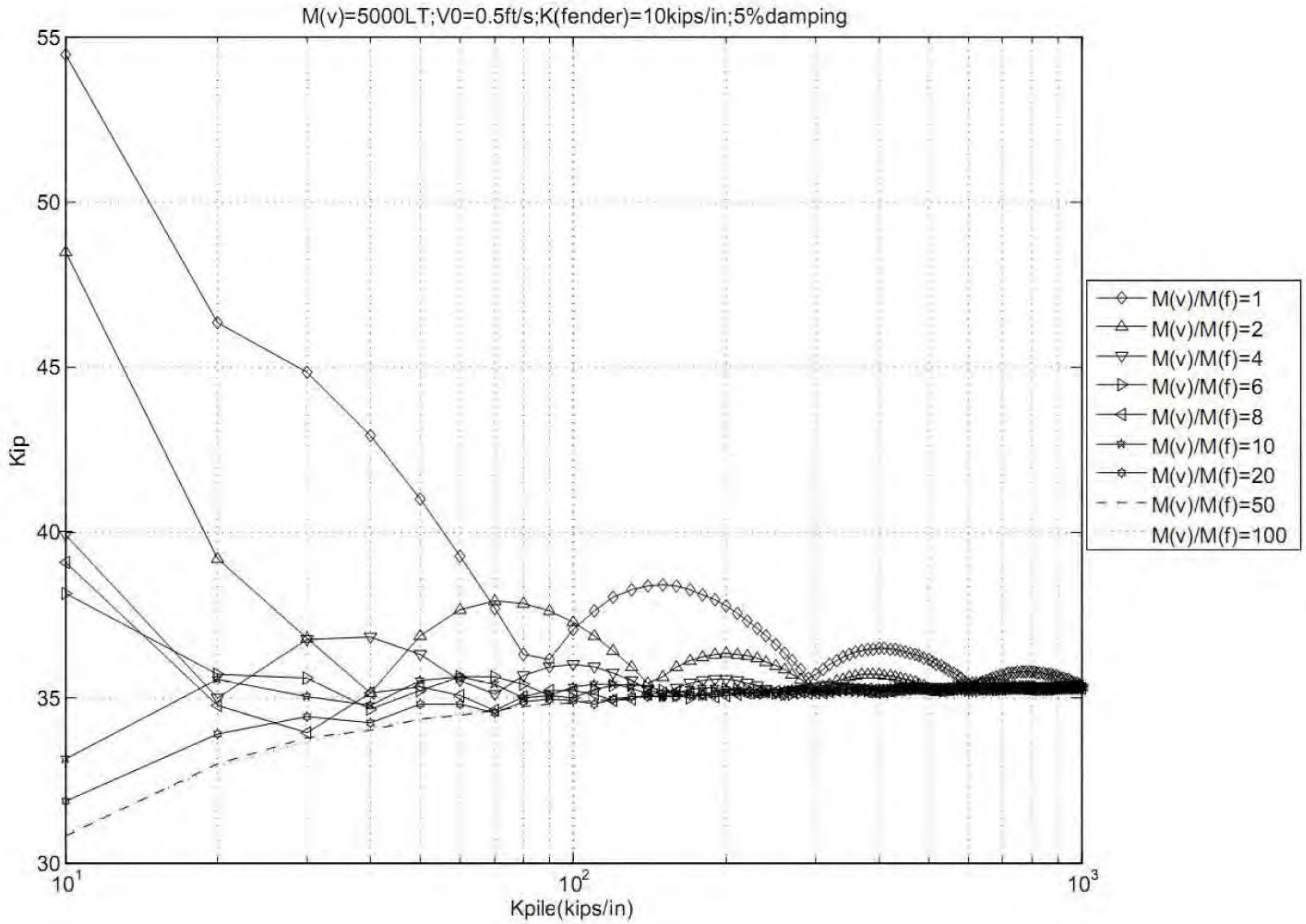


Fig. A.148 Reaction Force of the Piling System 2D-5b

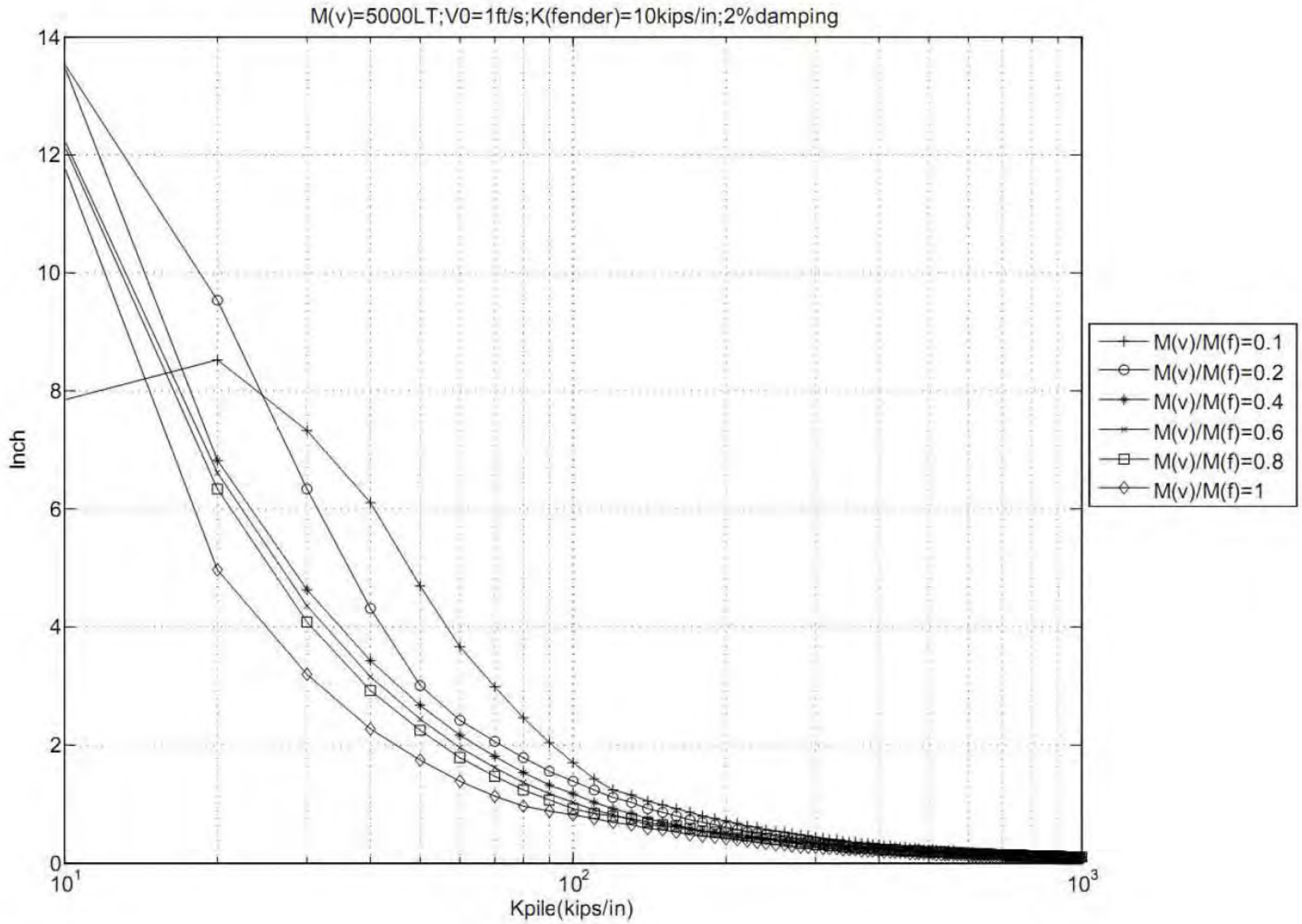


Fig. A.149 Displacement of the Piling System 2D-6a

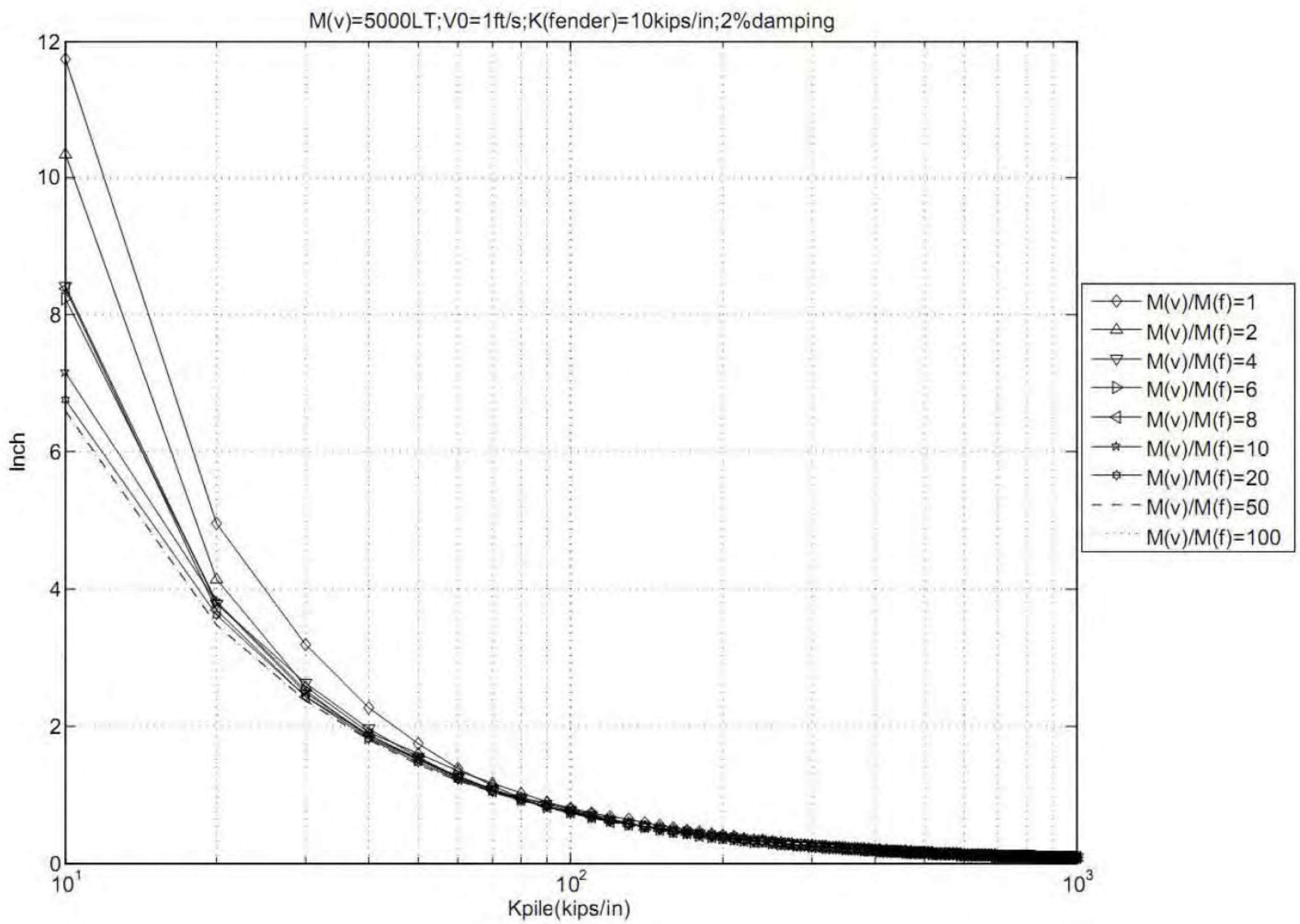


Fig. A.150 Displacement of the Piling System 2D-6b

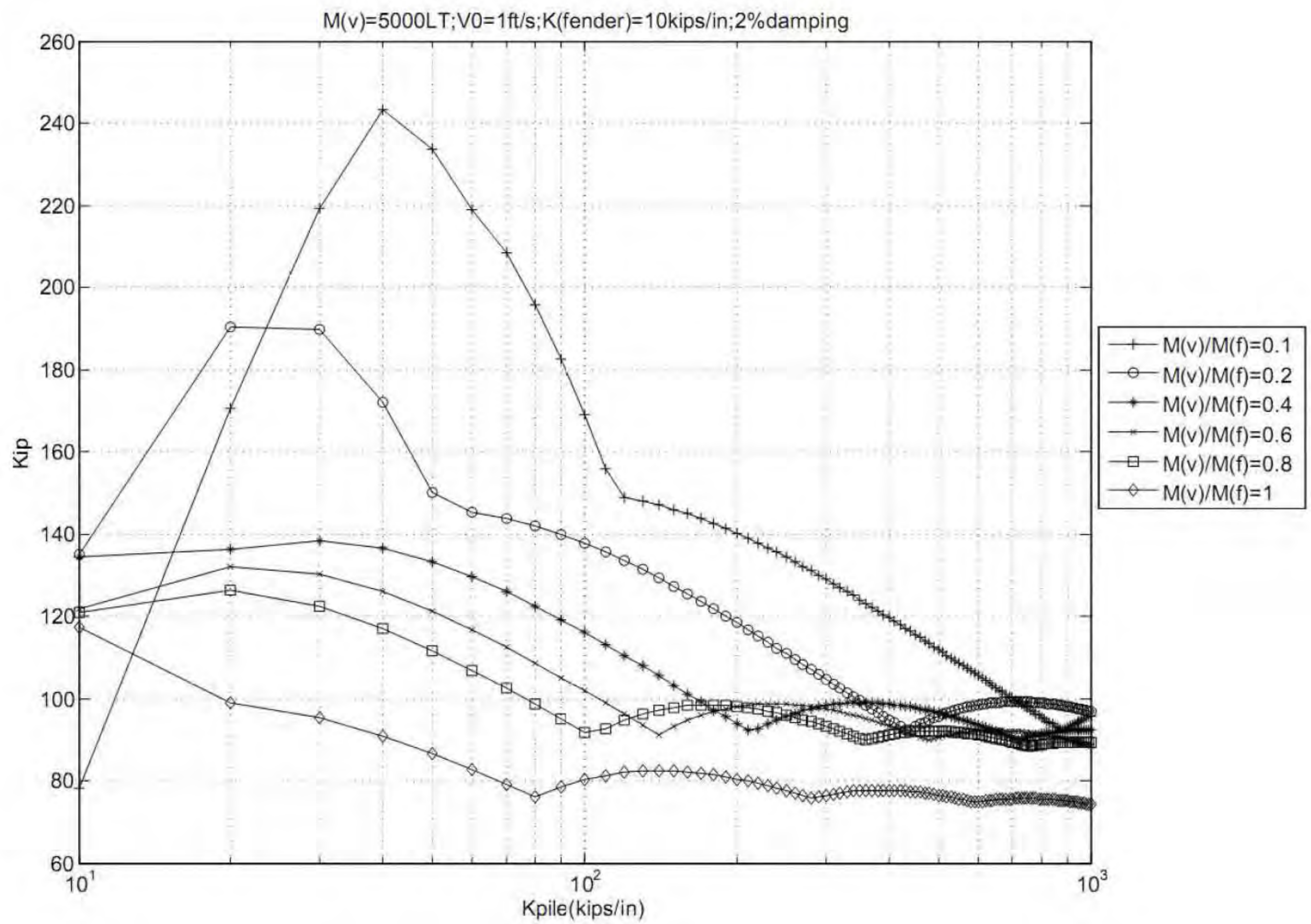


Fig. A.151 Reaction Force of the Piling System 2D-6a

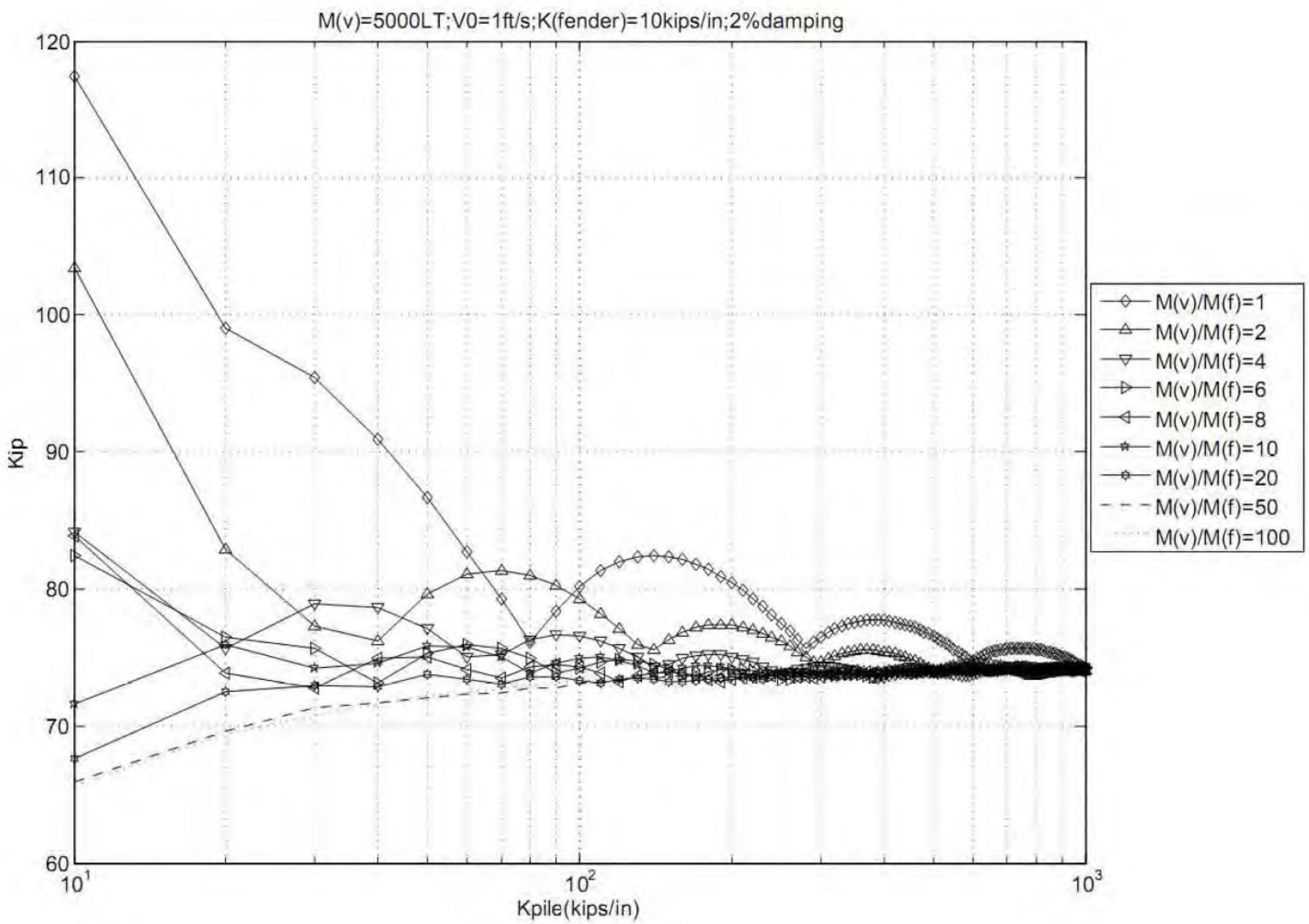


Fig. A.152 Reaction Force of the Piling System 2D-6b

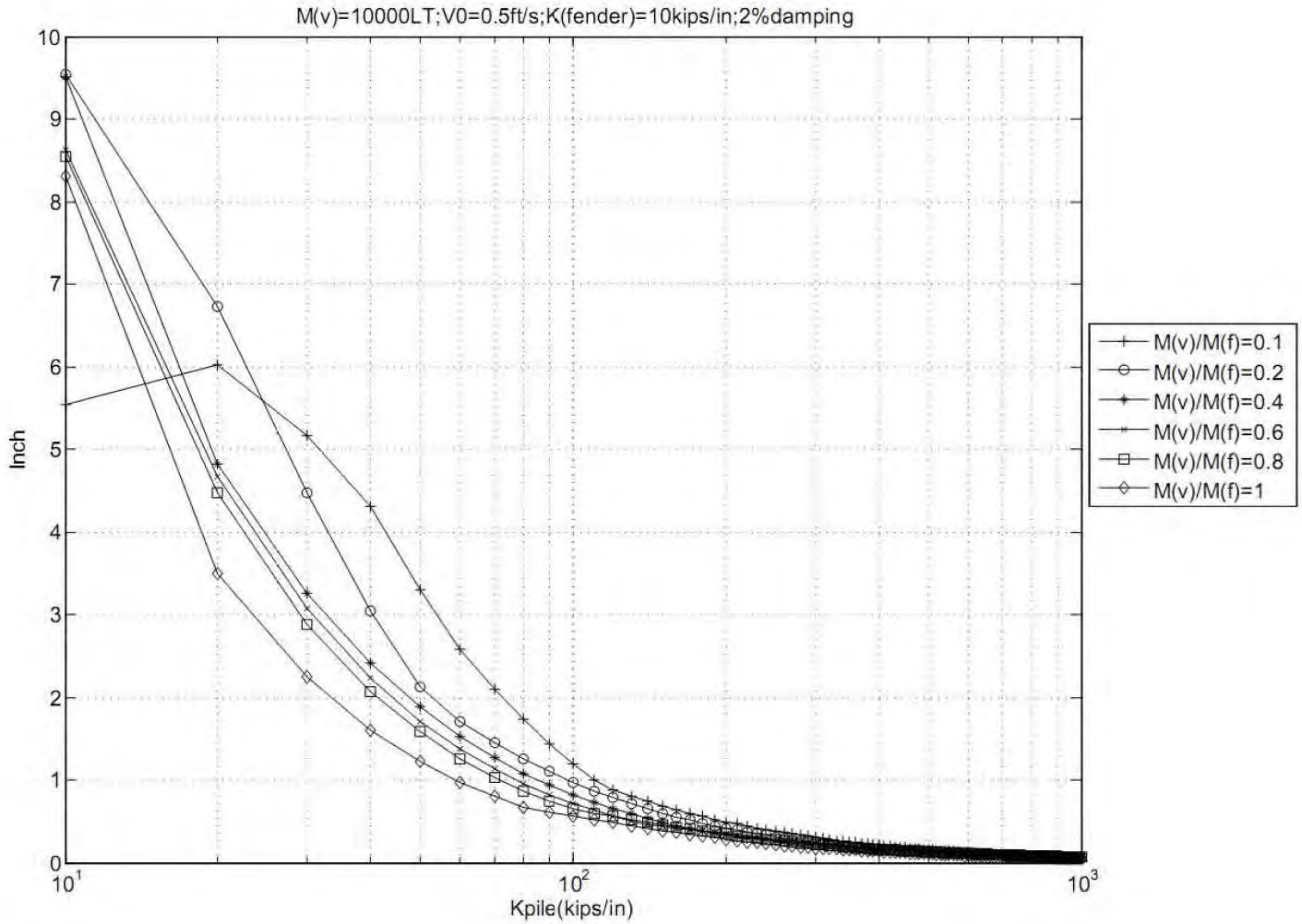


Fig. A.153 Displacement of the Piling System 2D-7a

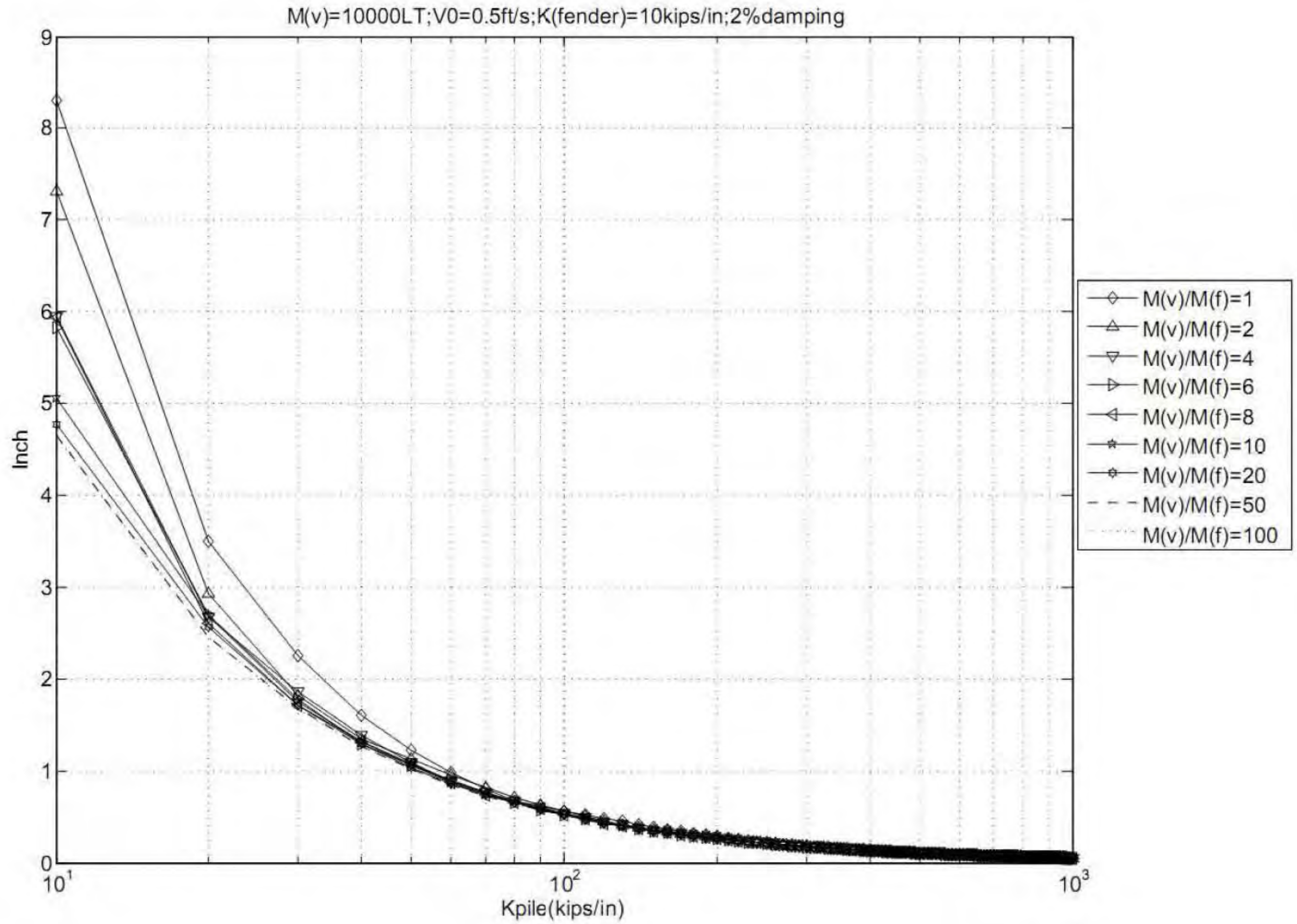


Fig. A.154 Displacement of the Piling System 2D-7b

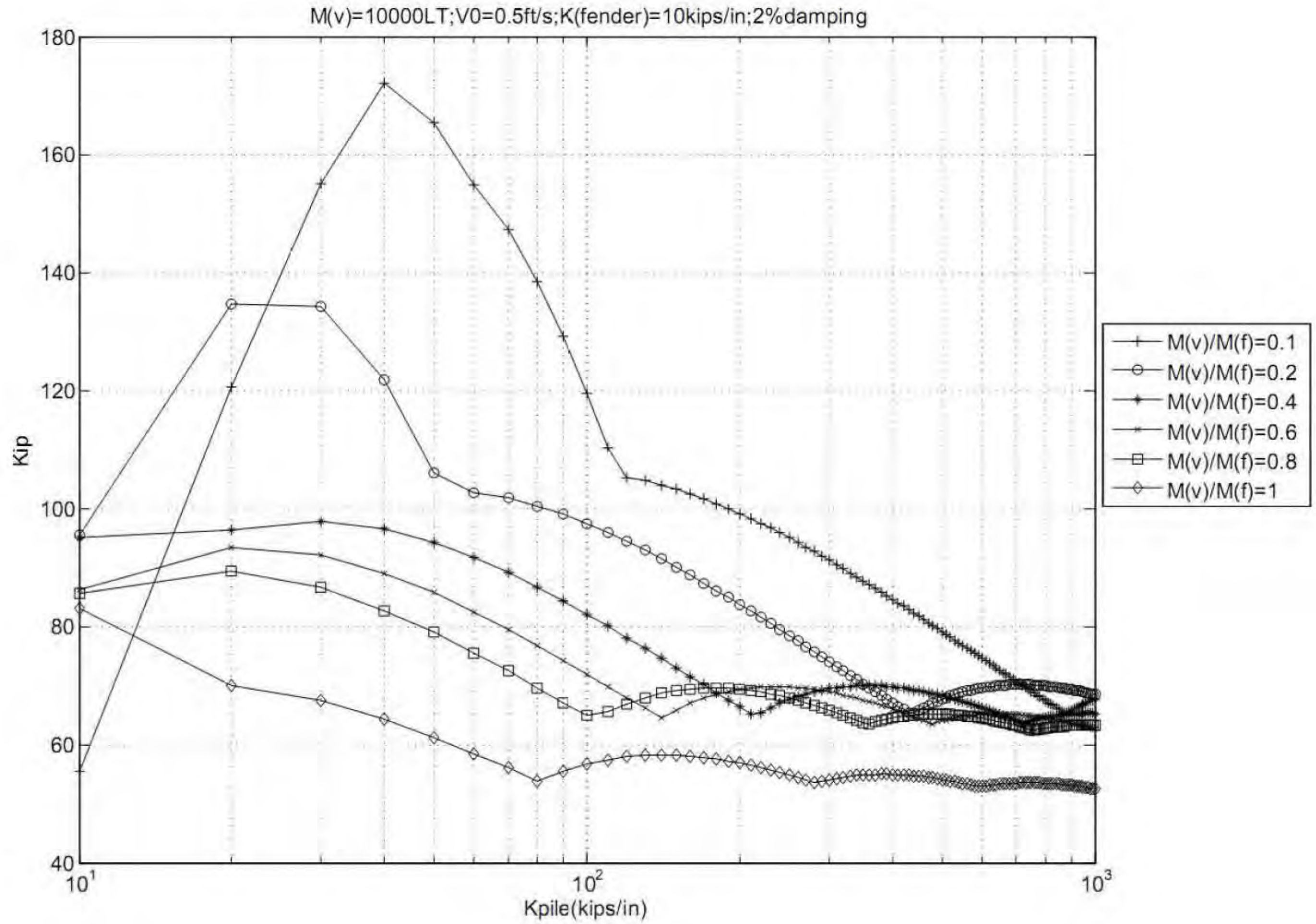


Fig. A.155 Reaction Force of the Piling System 2D-7a

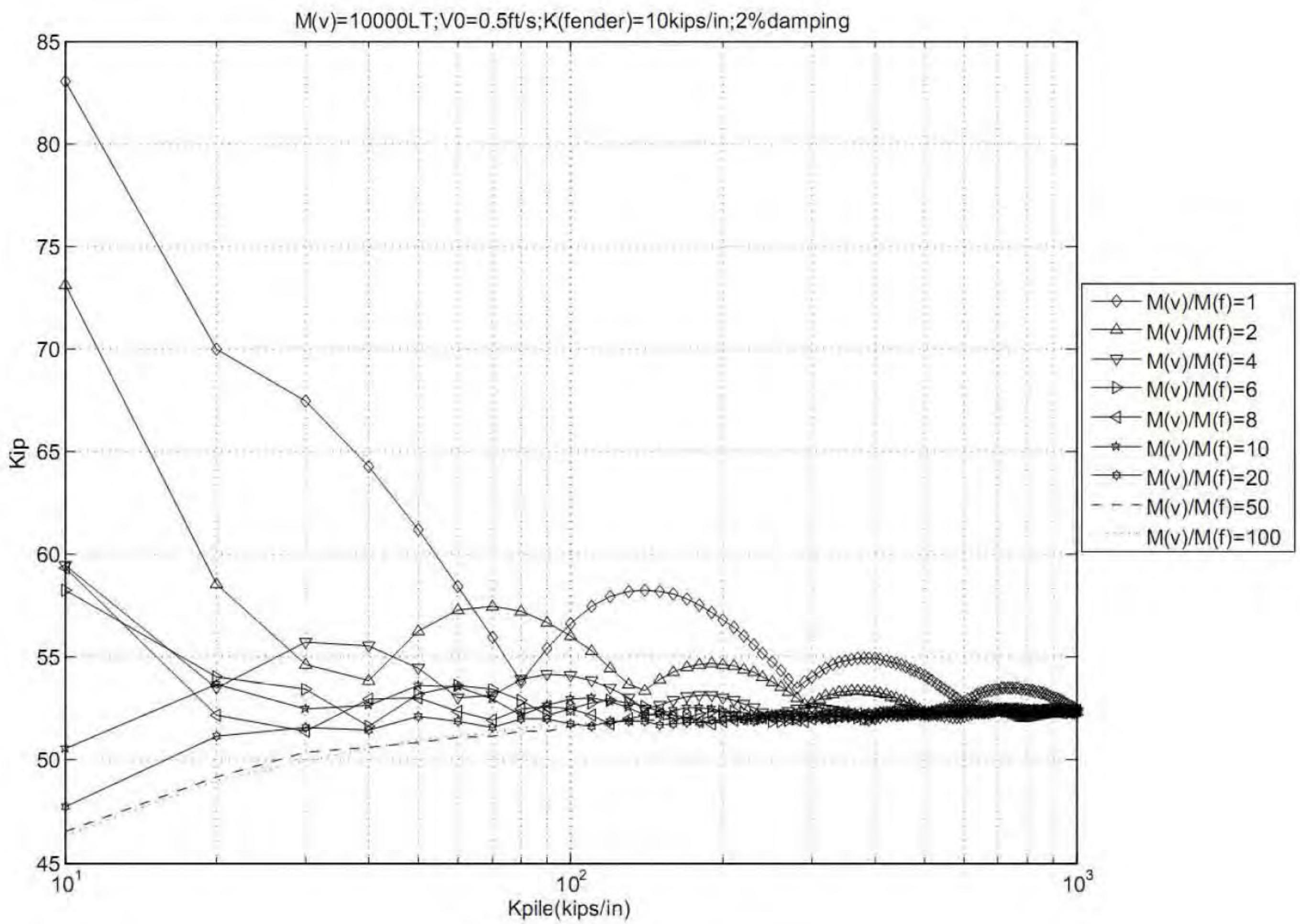


Fig. A.156 Reaction Force of the Piling System 2D-7b

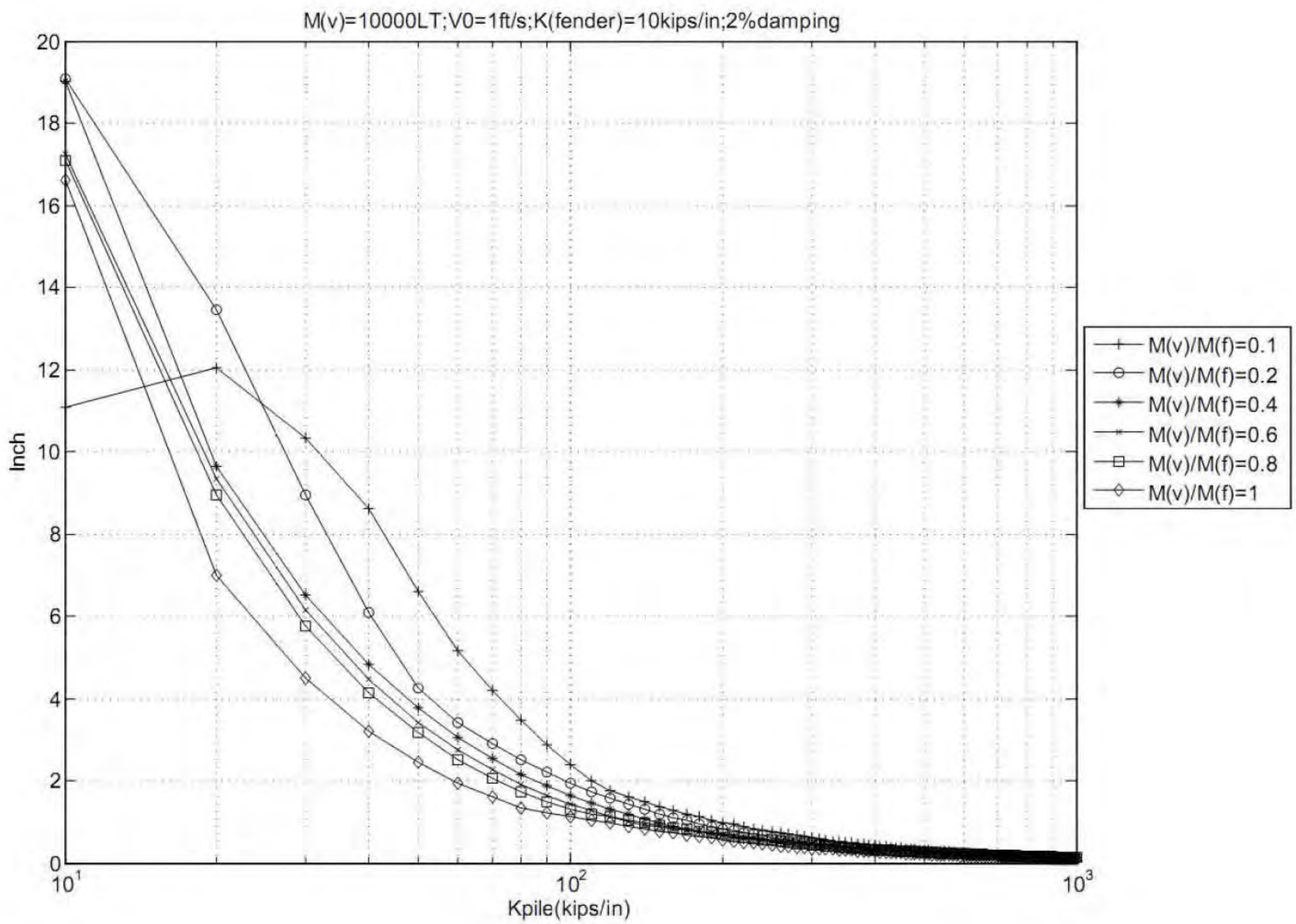


Fig. A.157 Displacement of the Piling System 2D-8a

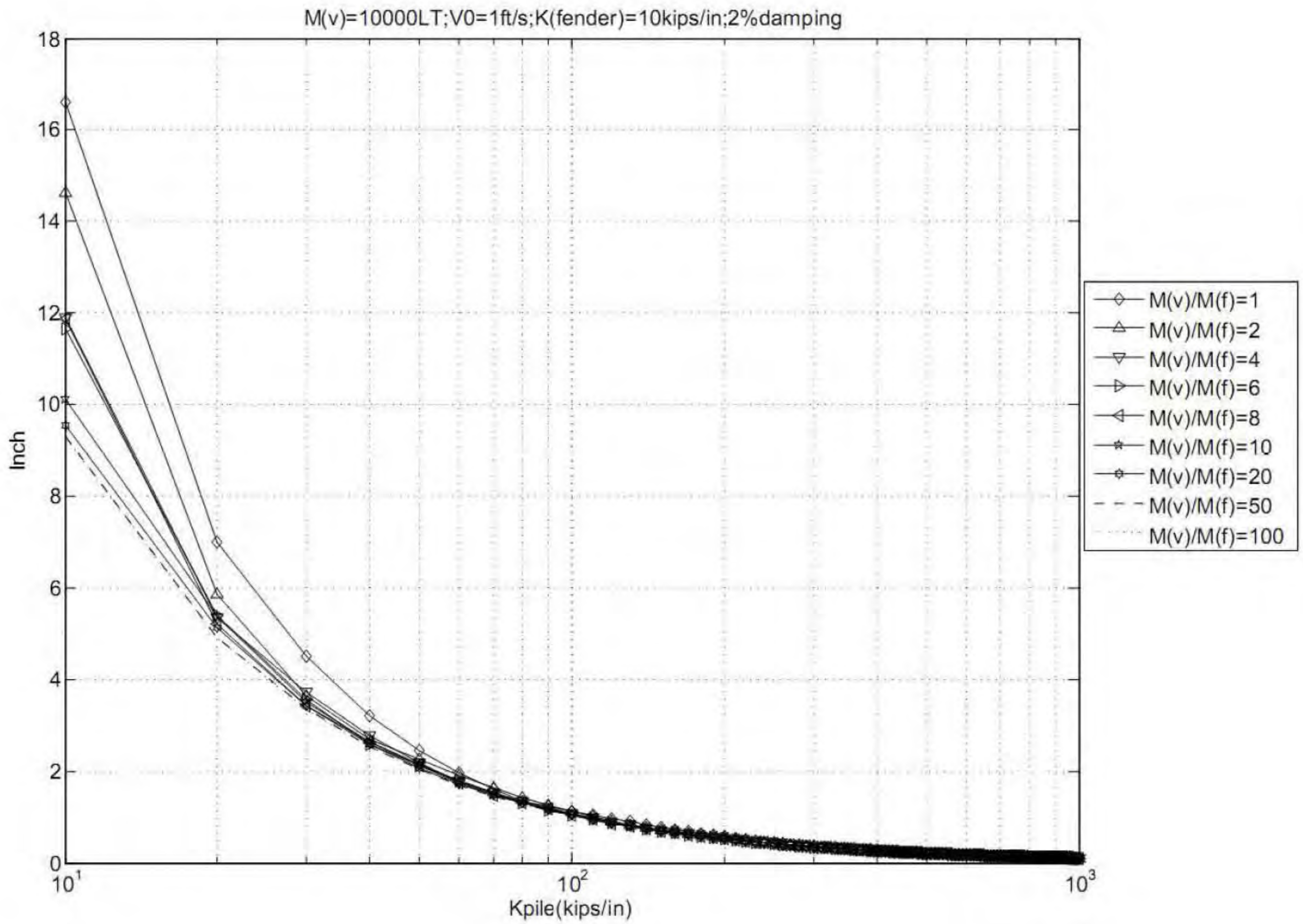


Fig. A.158 Displacement of the Piling System 2D-8b

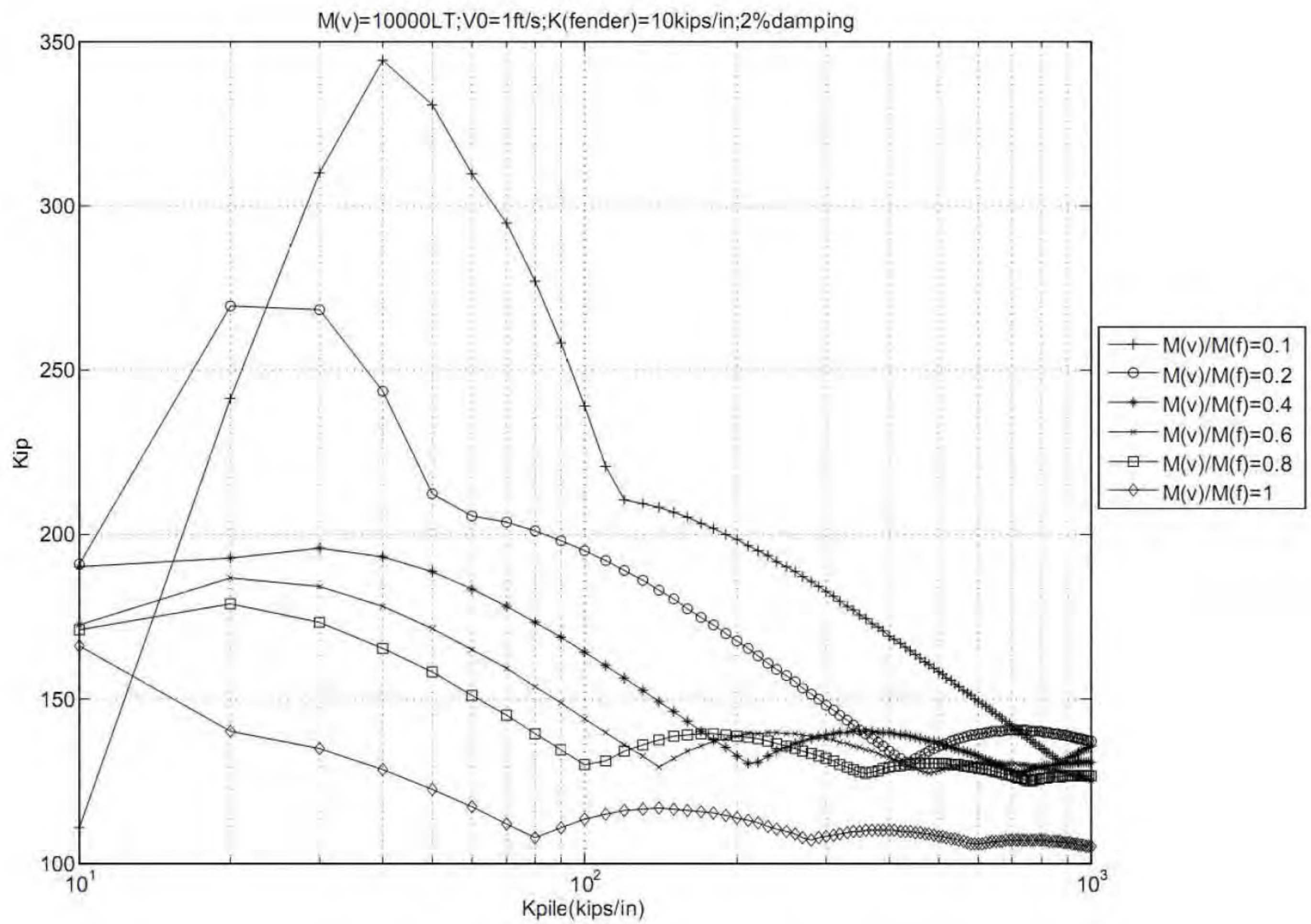


Fig. A.159 Reaction Force of the Piling System 2D-8a

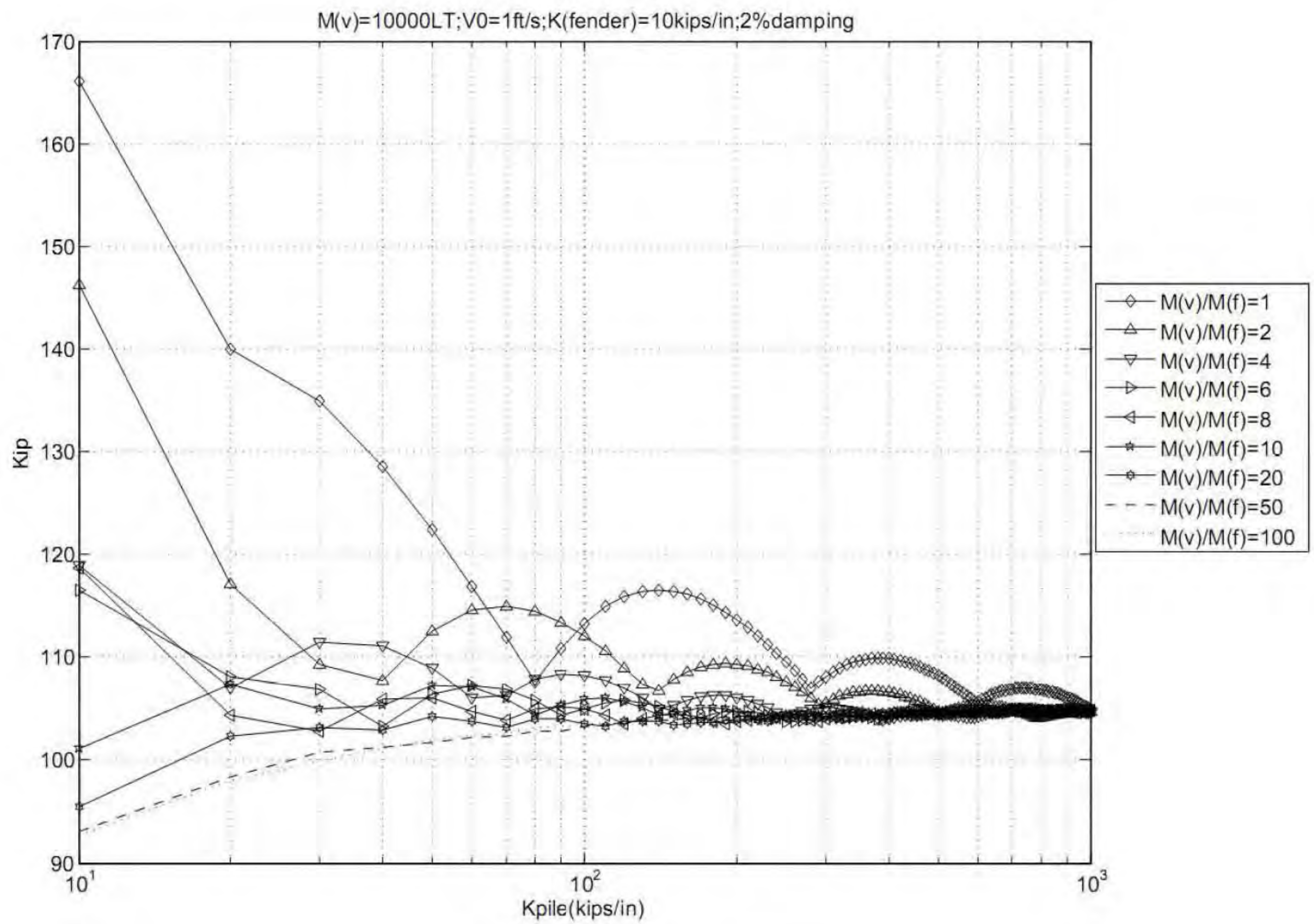


Fig. A.160 Reaction Force of the Piling System 2D-8b

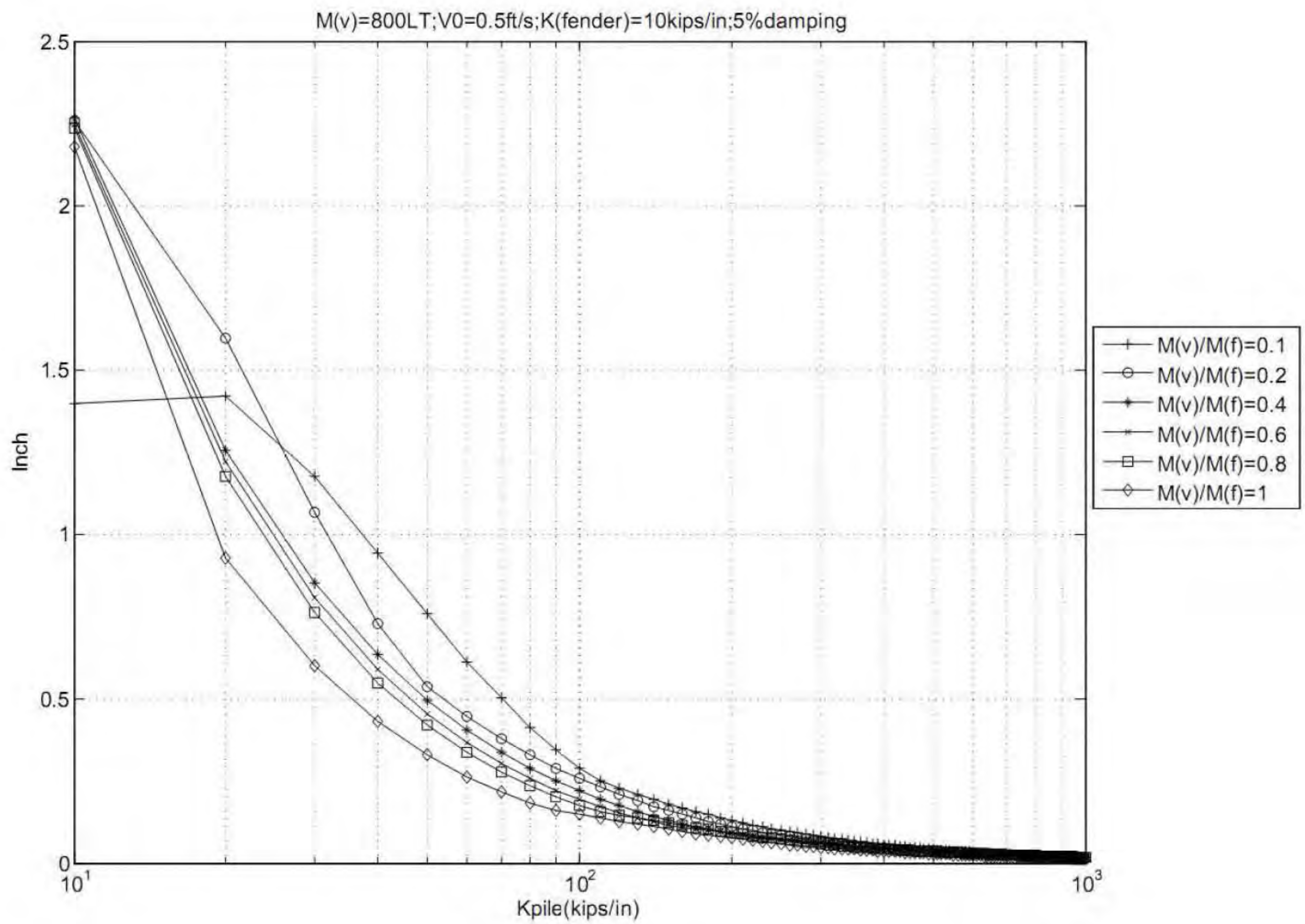


Fig. A.161 Displacement of the Piling System 2D-9a

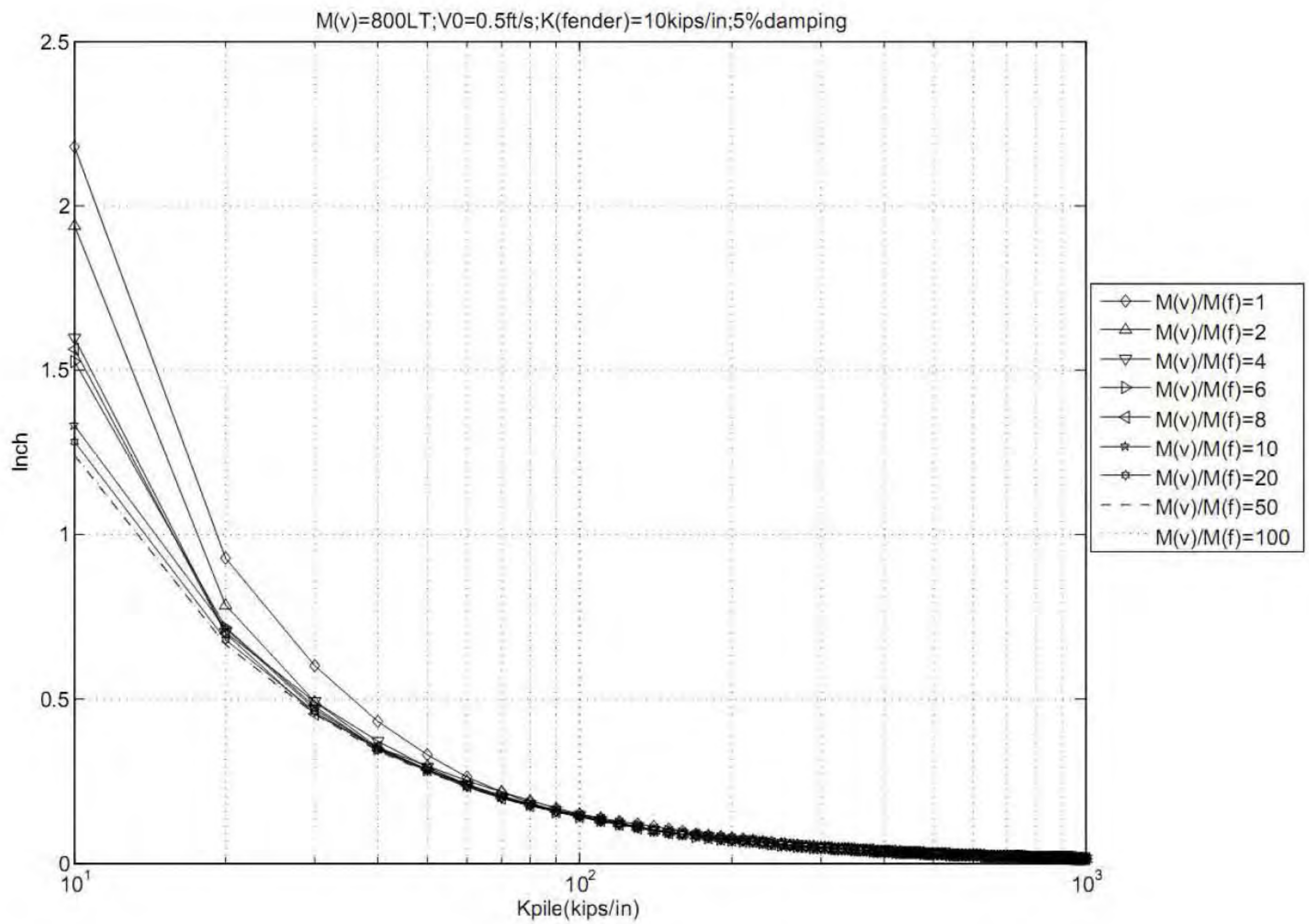


Fig. A.162 Displacement of the Piling System 2D-9b

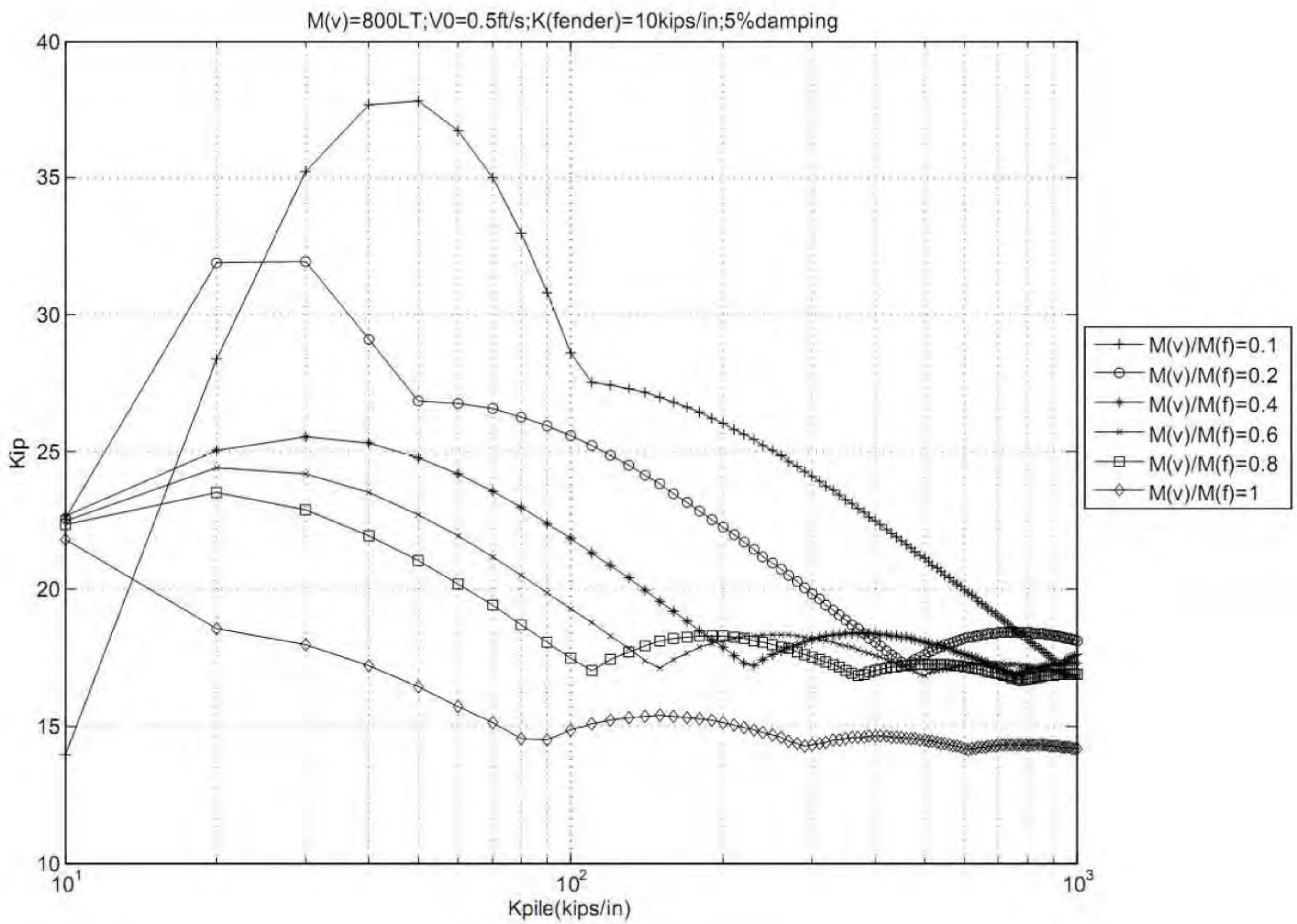


Fig. A.163 Reaction Force of the Piling System 2D-9a

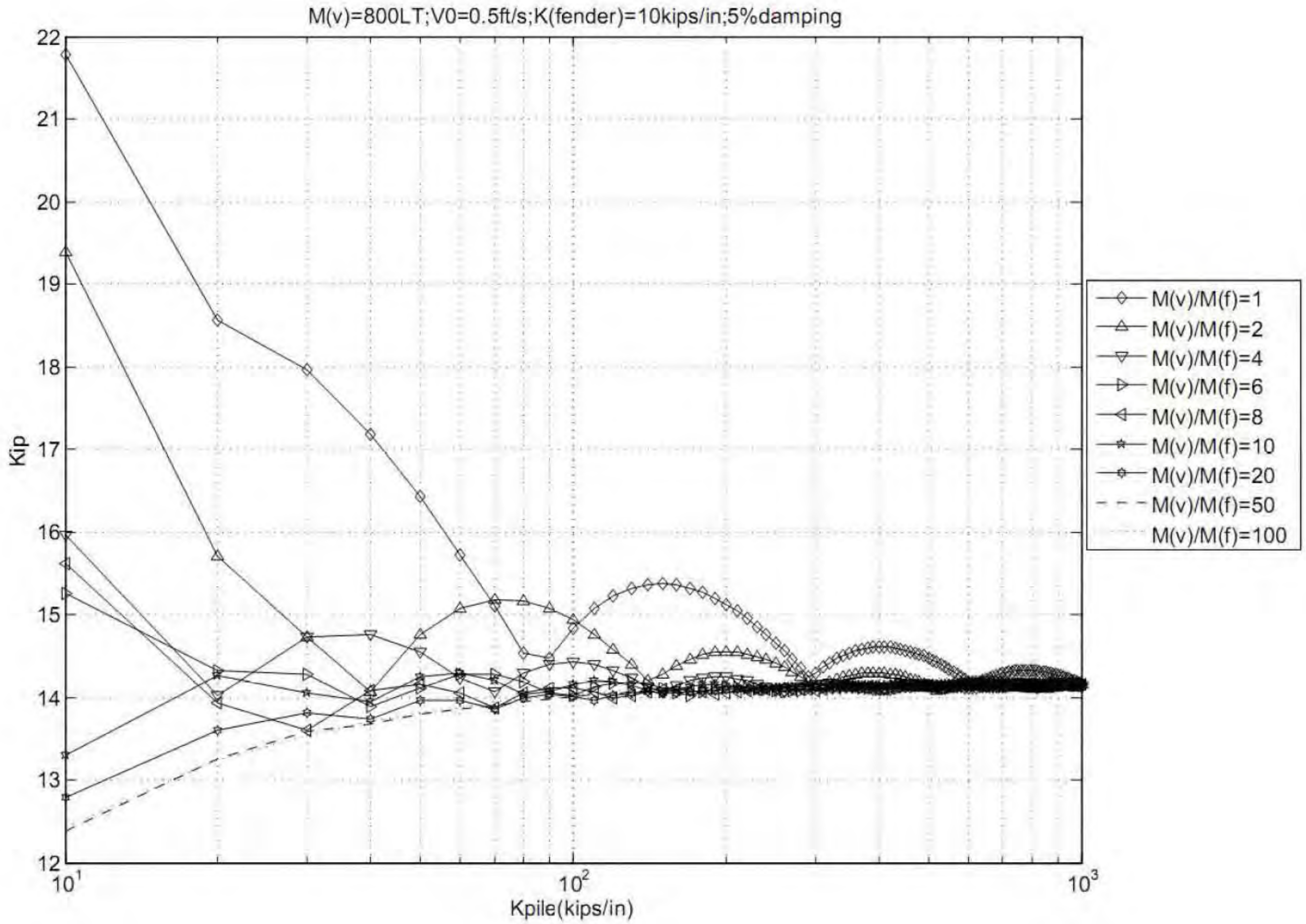


Fig. A.164 Reaction Force of the Piling System 2D-9b

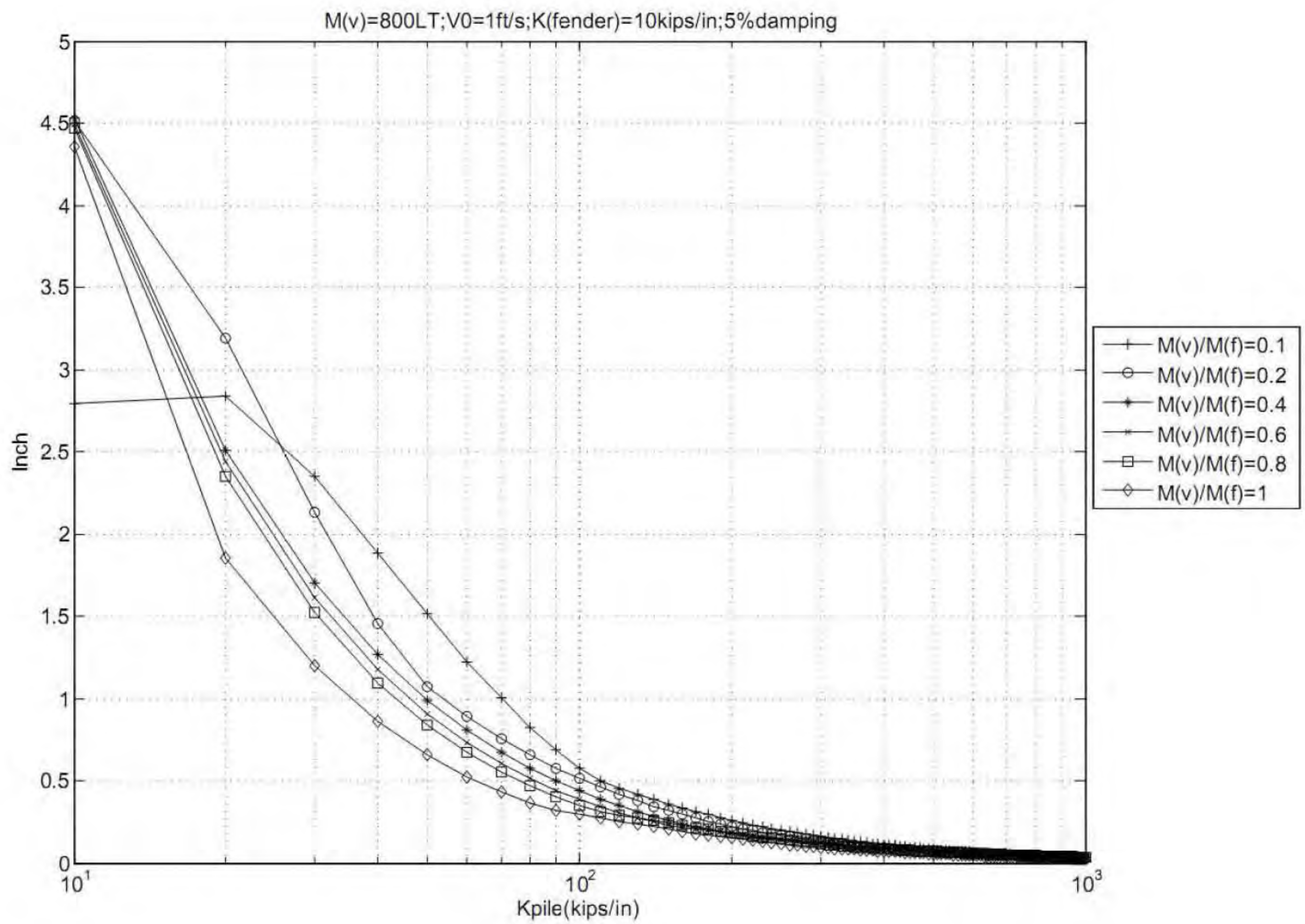


Fig. A.165 Displacement of the Piling System 2D-10a

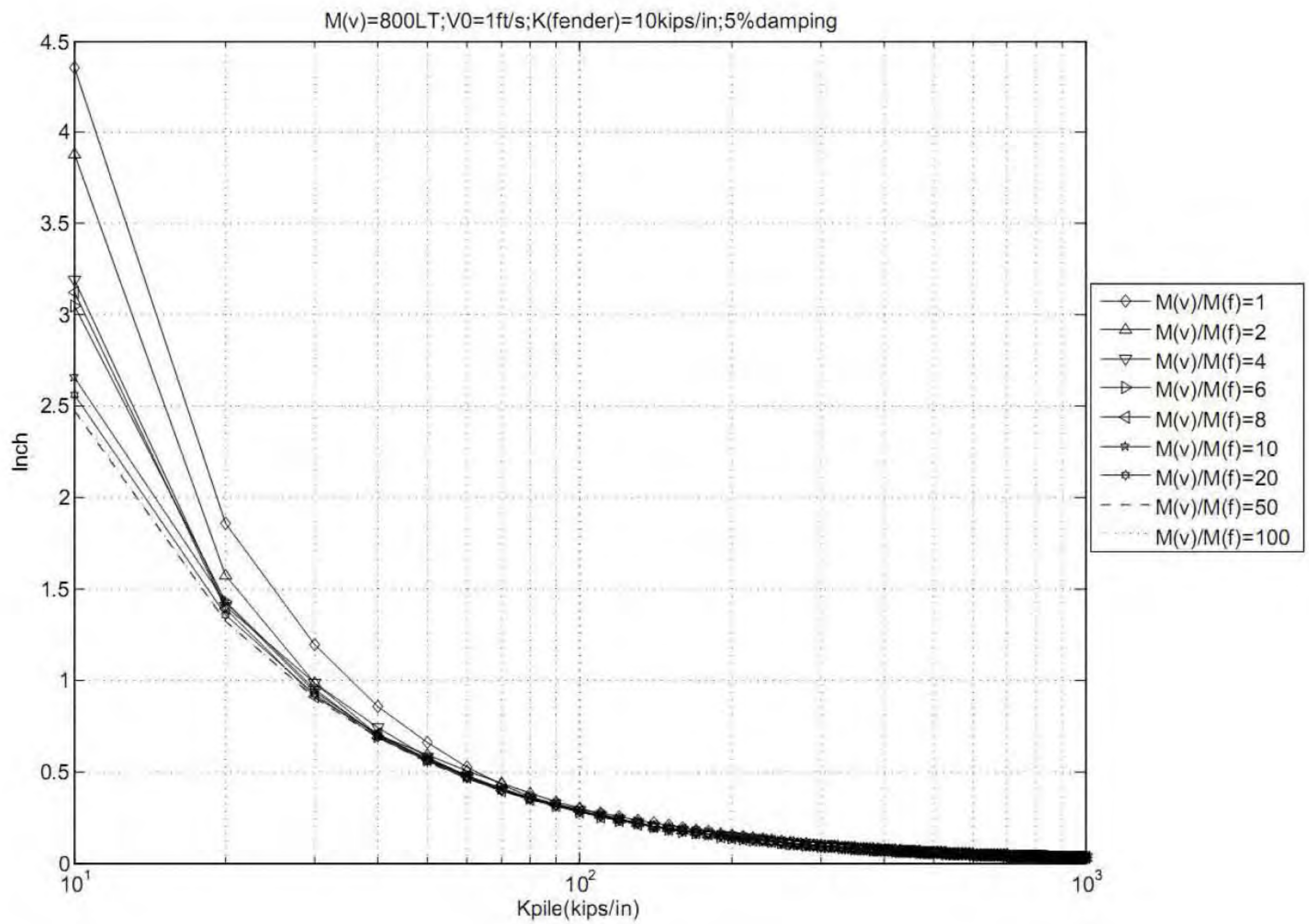


Fig. A.166 Displacement of the Piling System 2D-10b

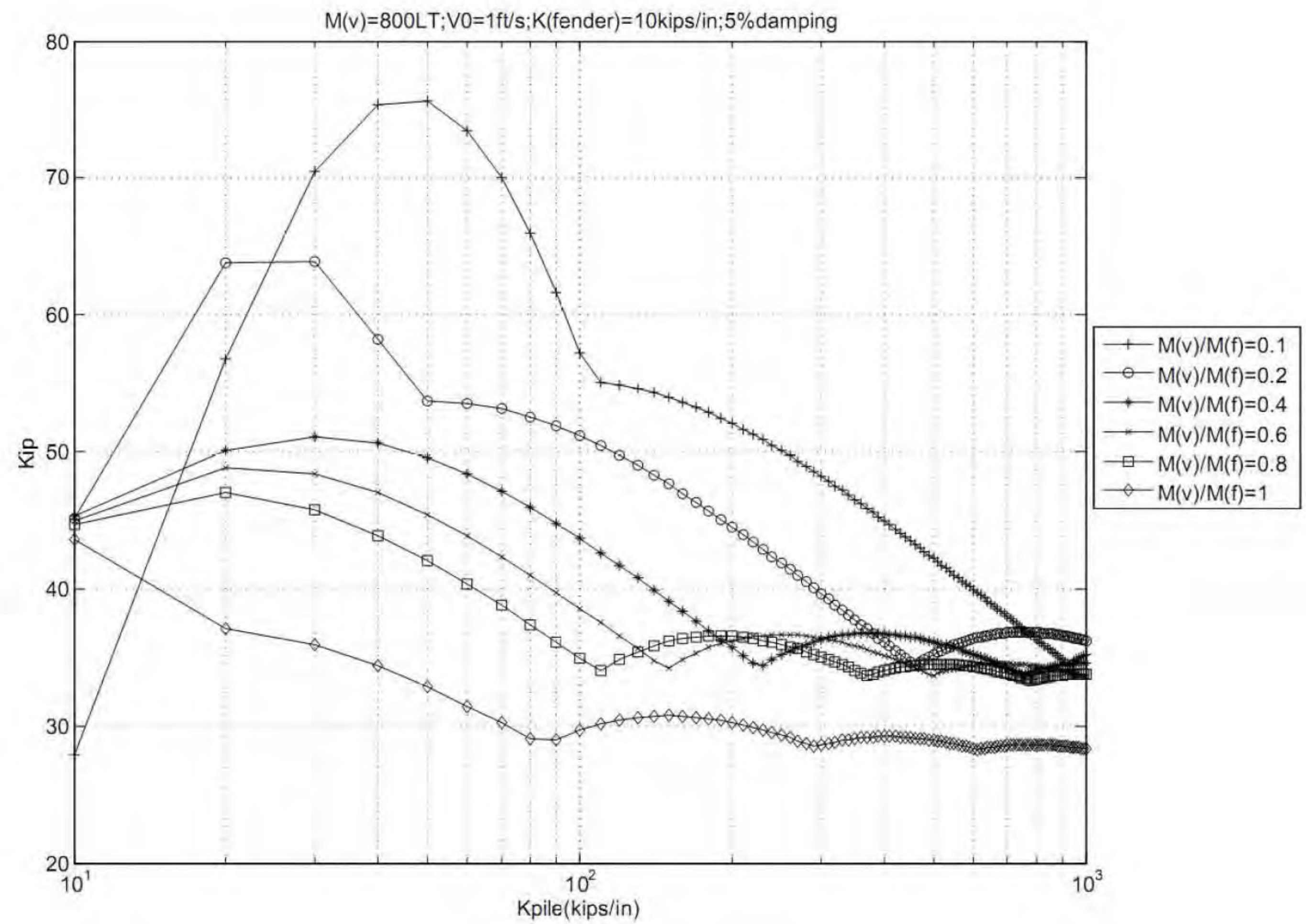


Fig. A.167 Reaction Force of the Piling System 2D-10a

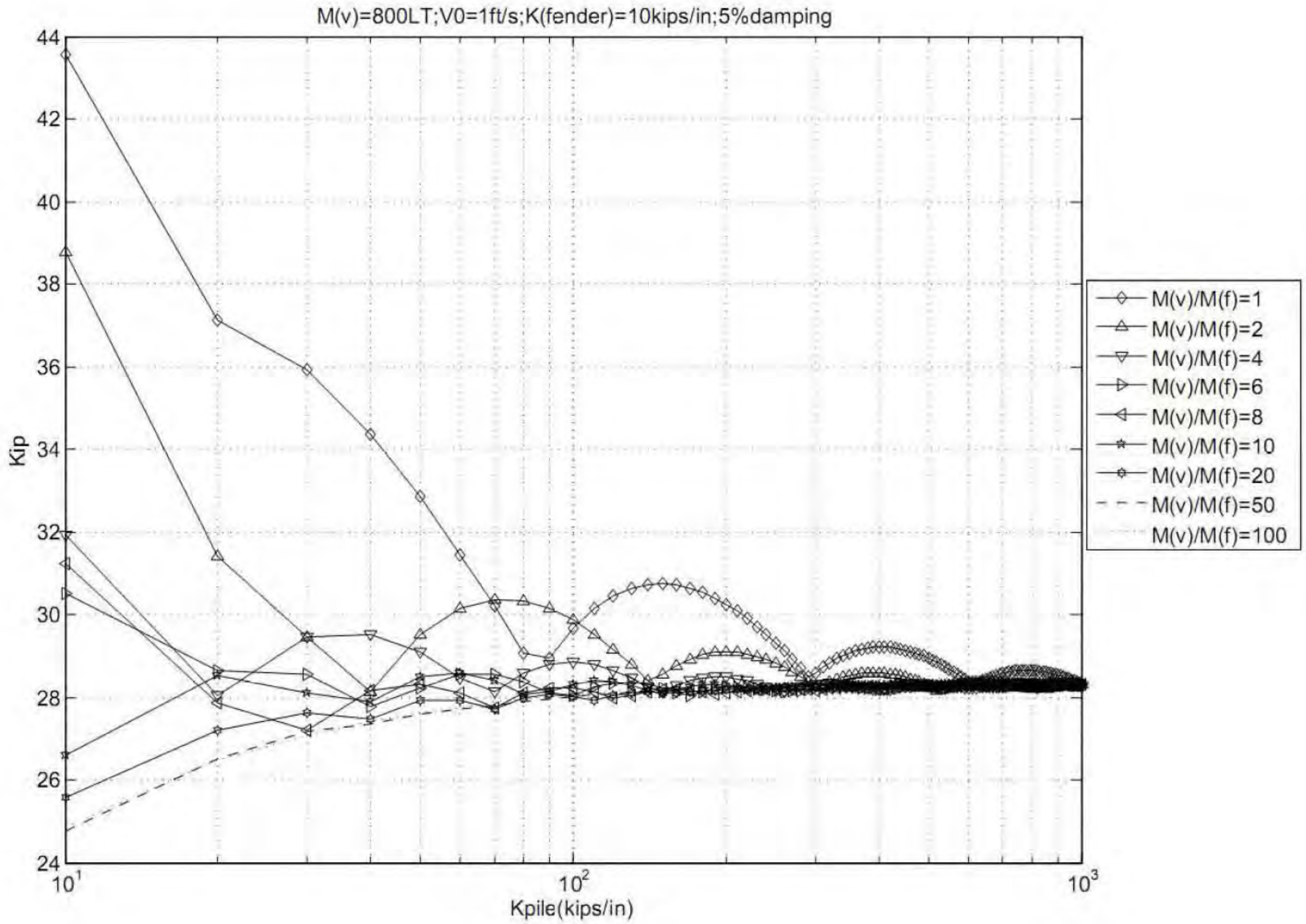


Fig. A.168 Reaction Force of the Piling System 2D-10b

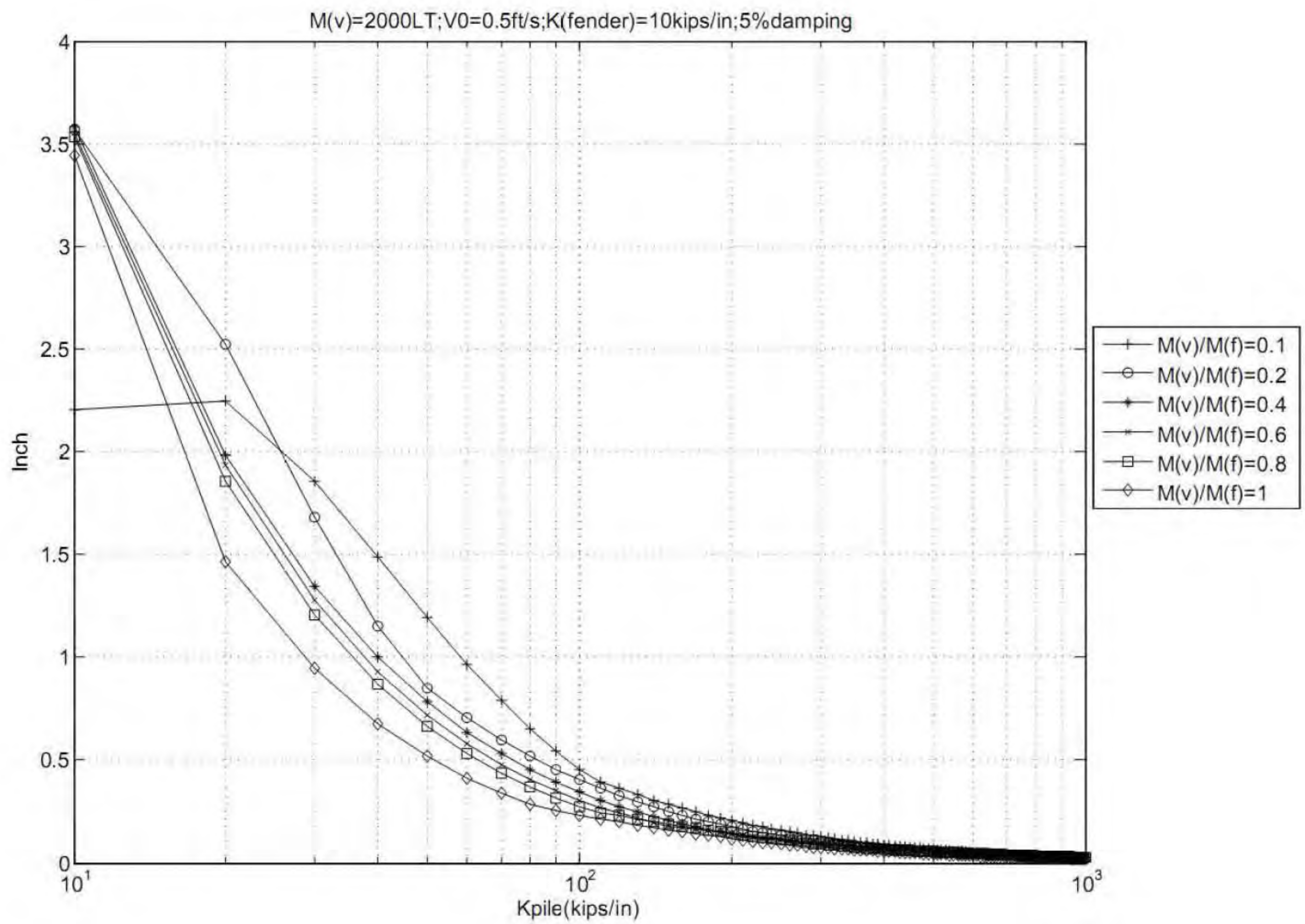


Fig. A.169 Displacement of the Piling System 2D-11a

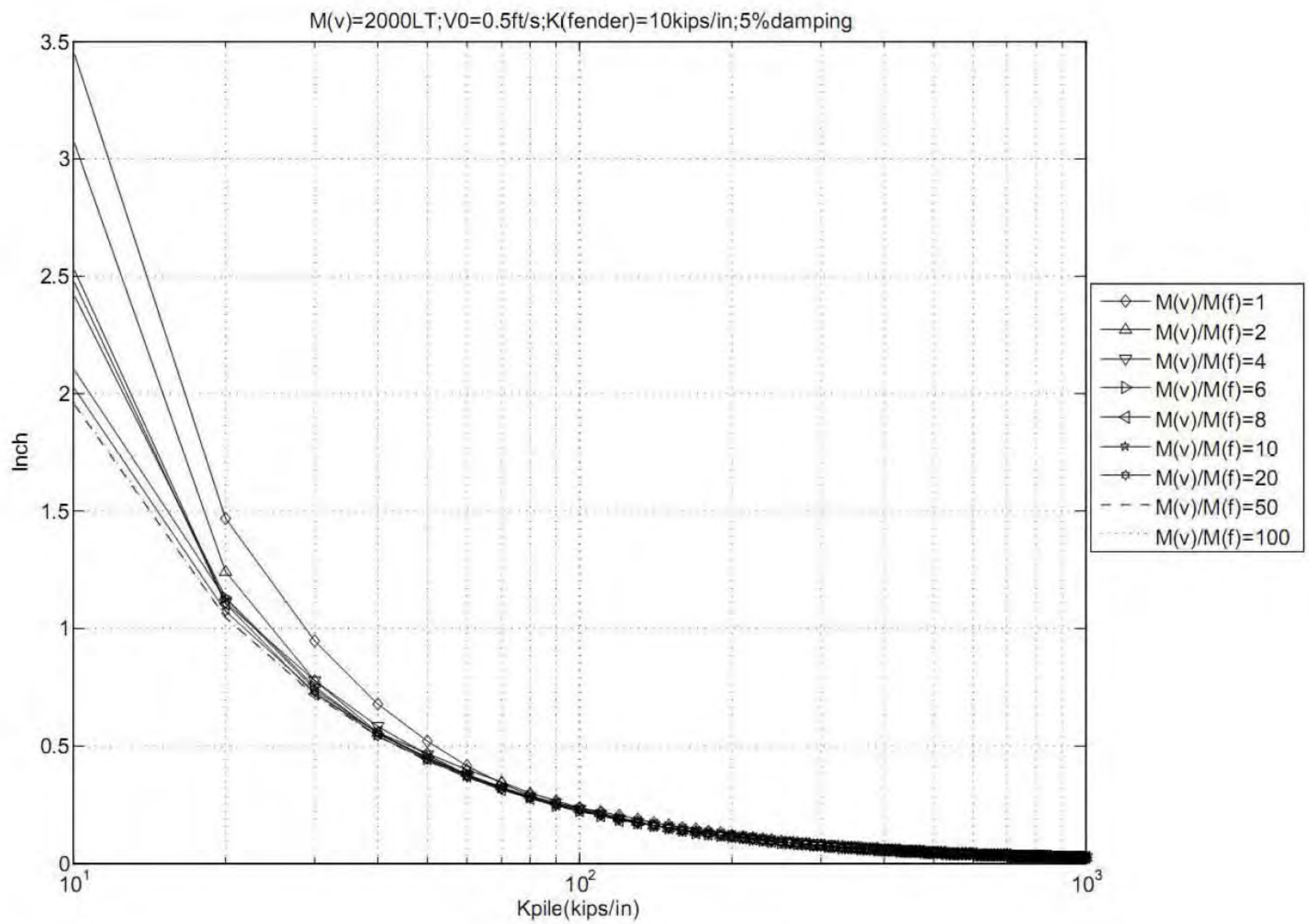


Fig. A.170 Displacement of the Piling System 2D-11b

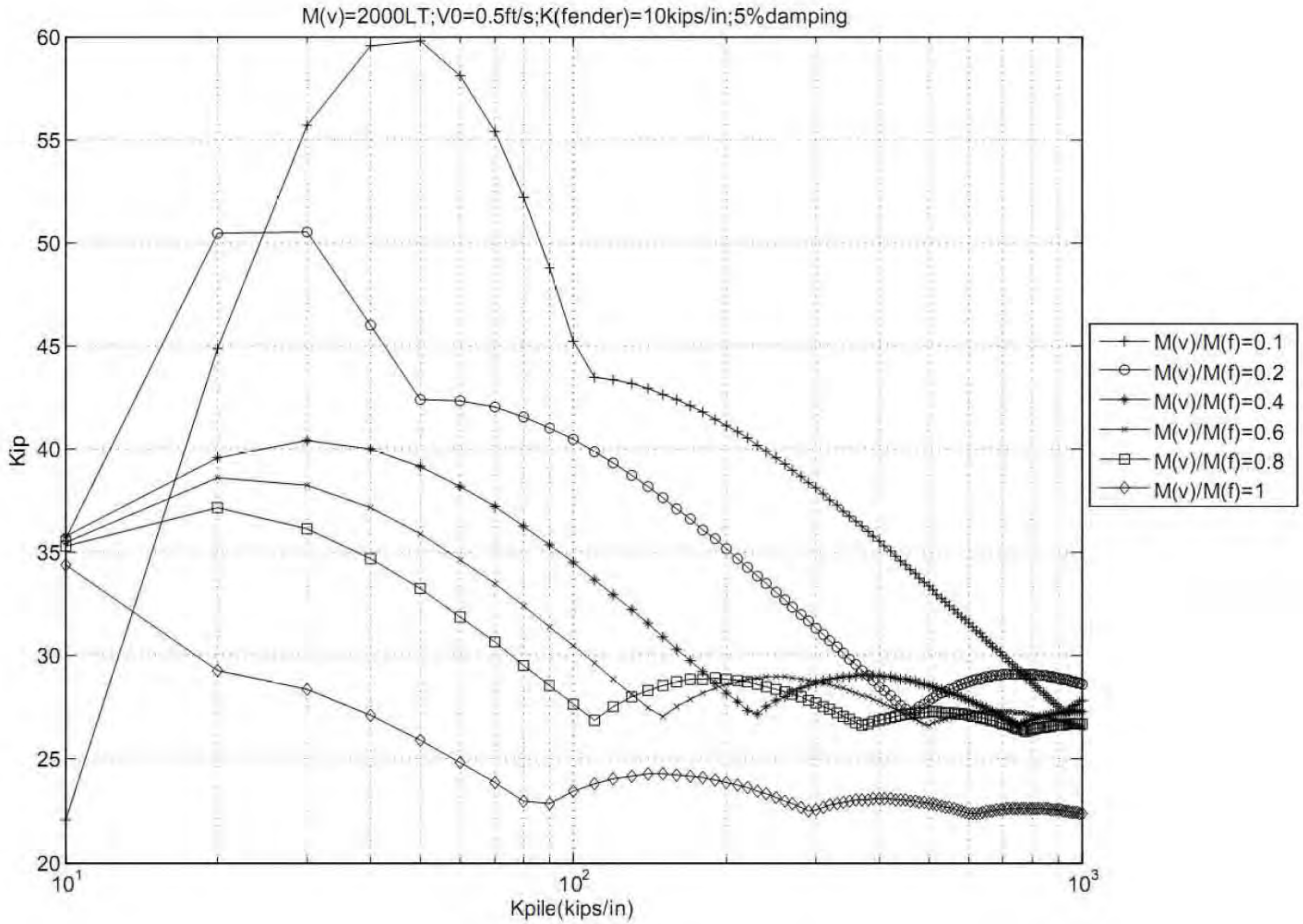


Fig. A.171 Reaction Force of the Piling System 2D-11a

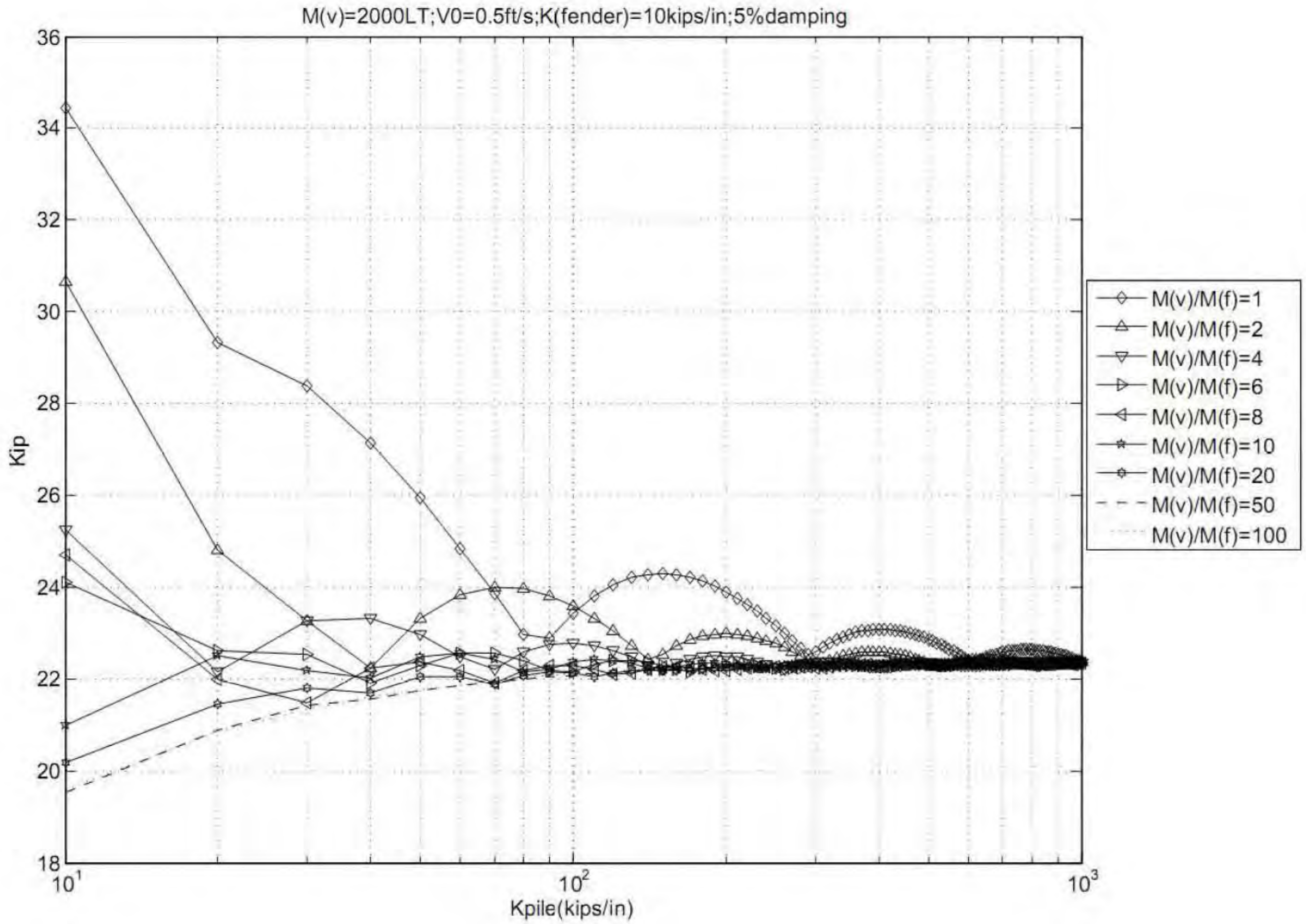


Fig. A.172 Reaction Force of the Piling System 2D-11b

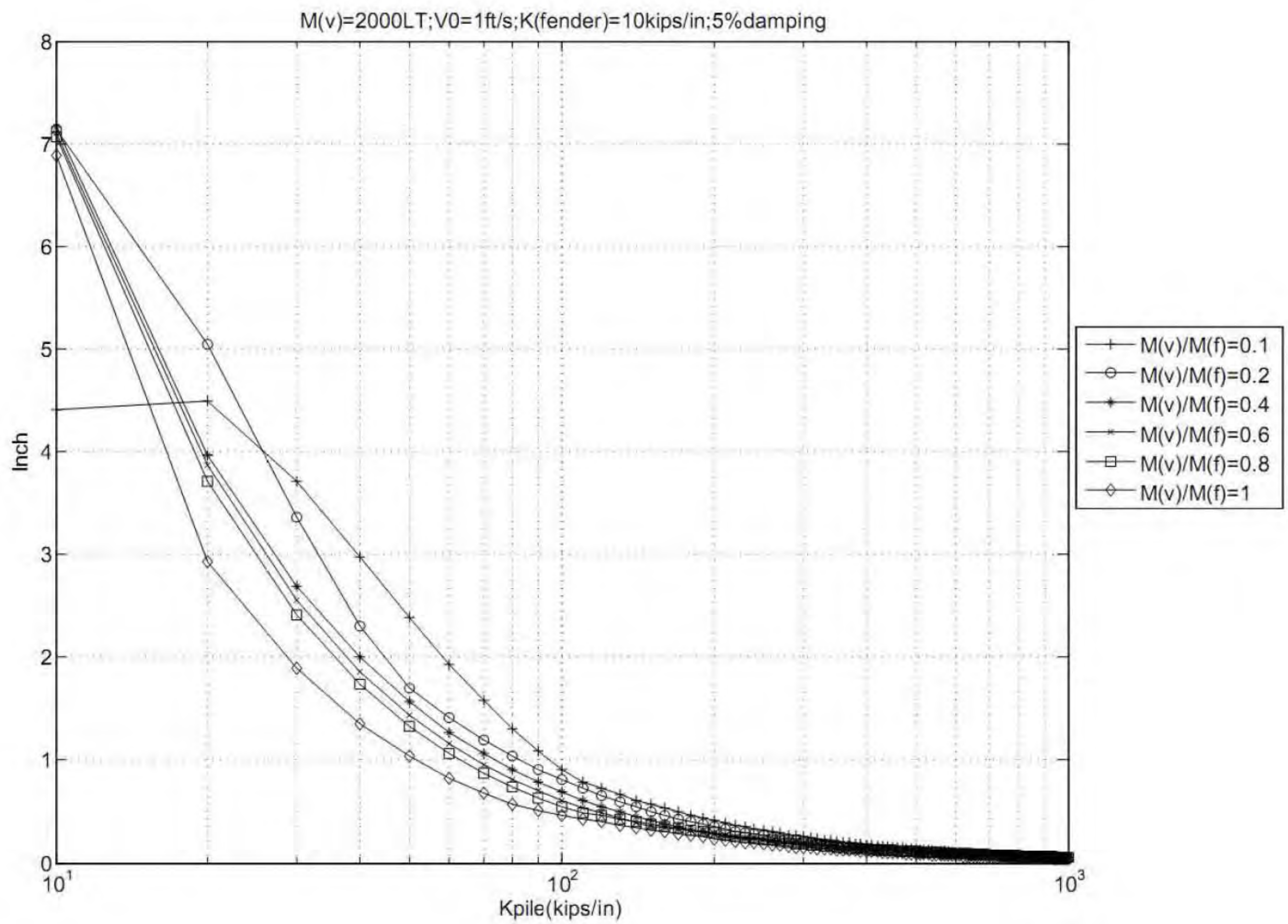


Fig. A.173 Displacement of the Piling System 2D-12a

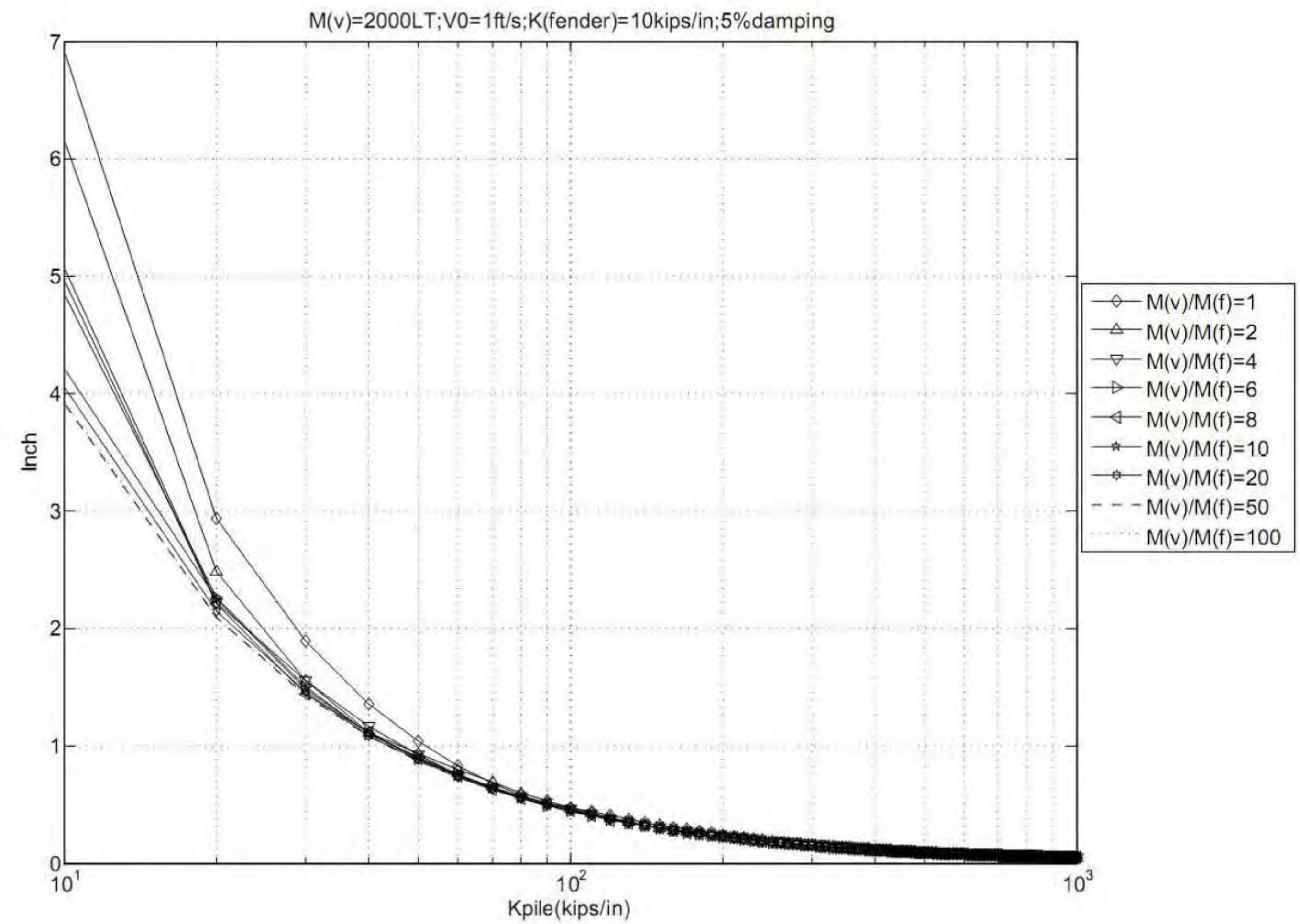


Fig. A.174 Displacement of the Piling System 2D-12b

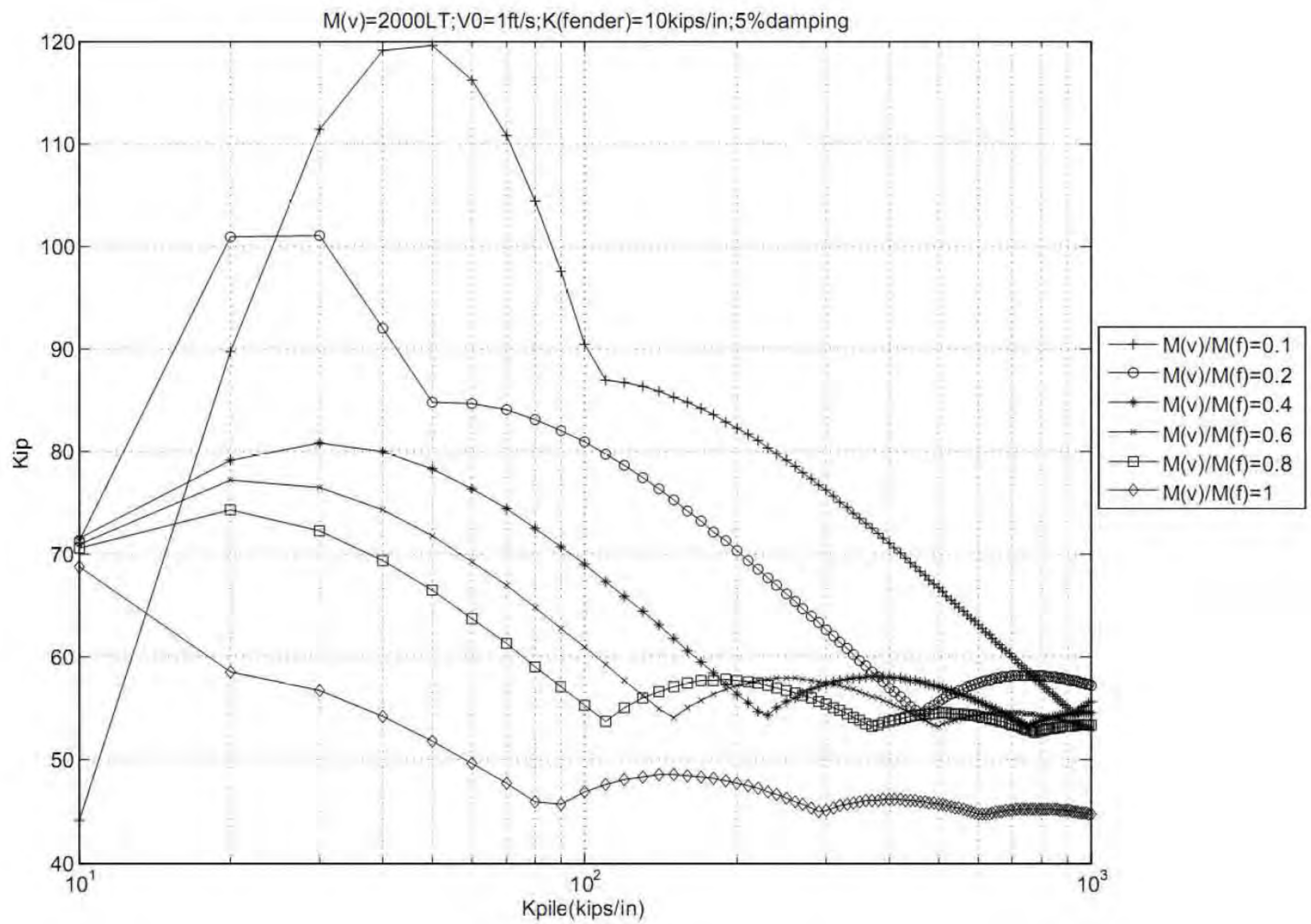


Fig. A.175 Reaction Force of the Piling System 2D-12a

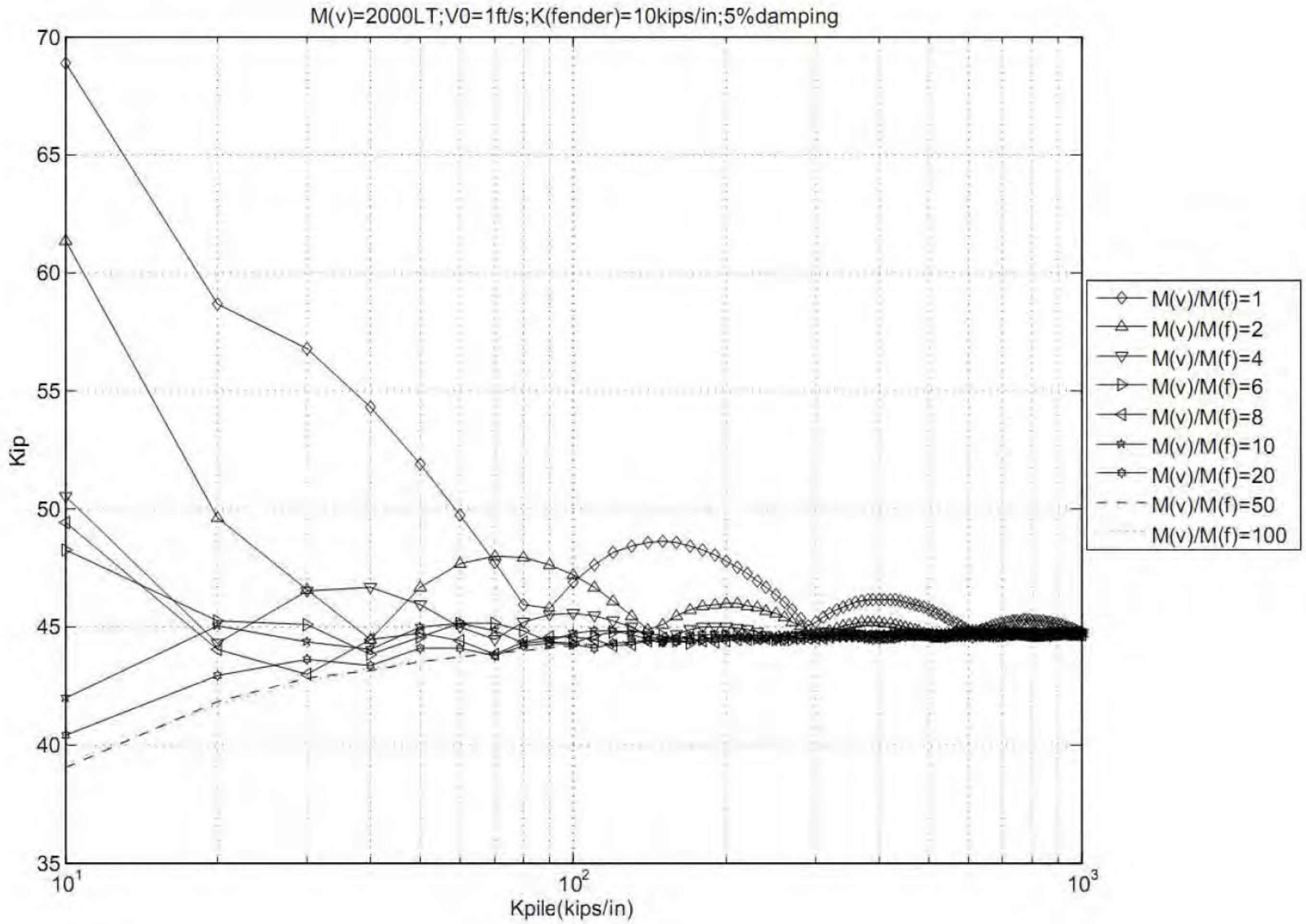


Fig. A.176 Reaction Force of the Piling System 2D-12b

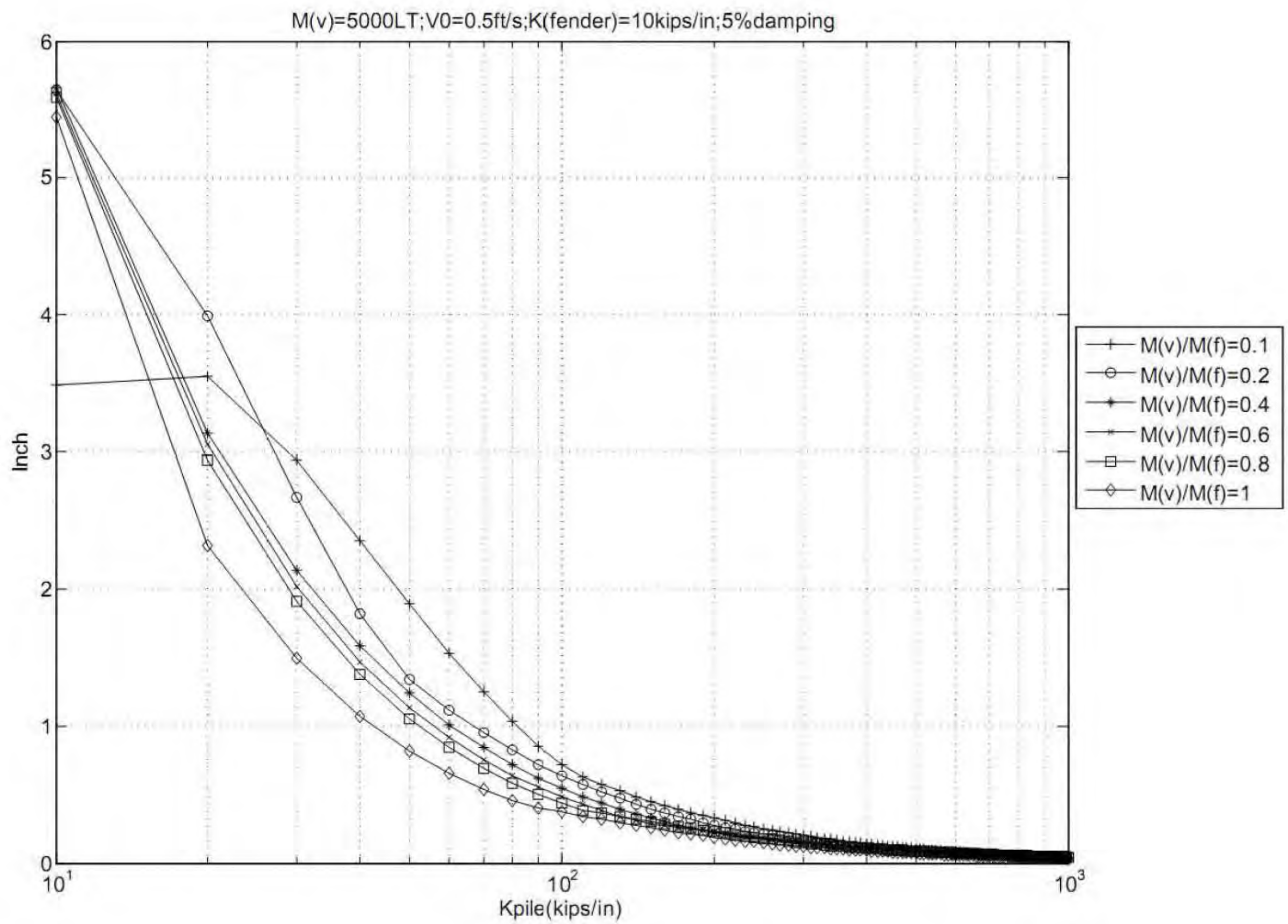


Fig. A.177 Displacement of the Piling System 2D-13a

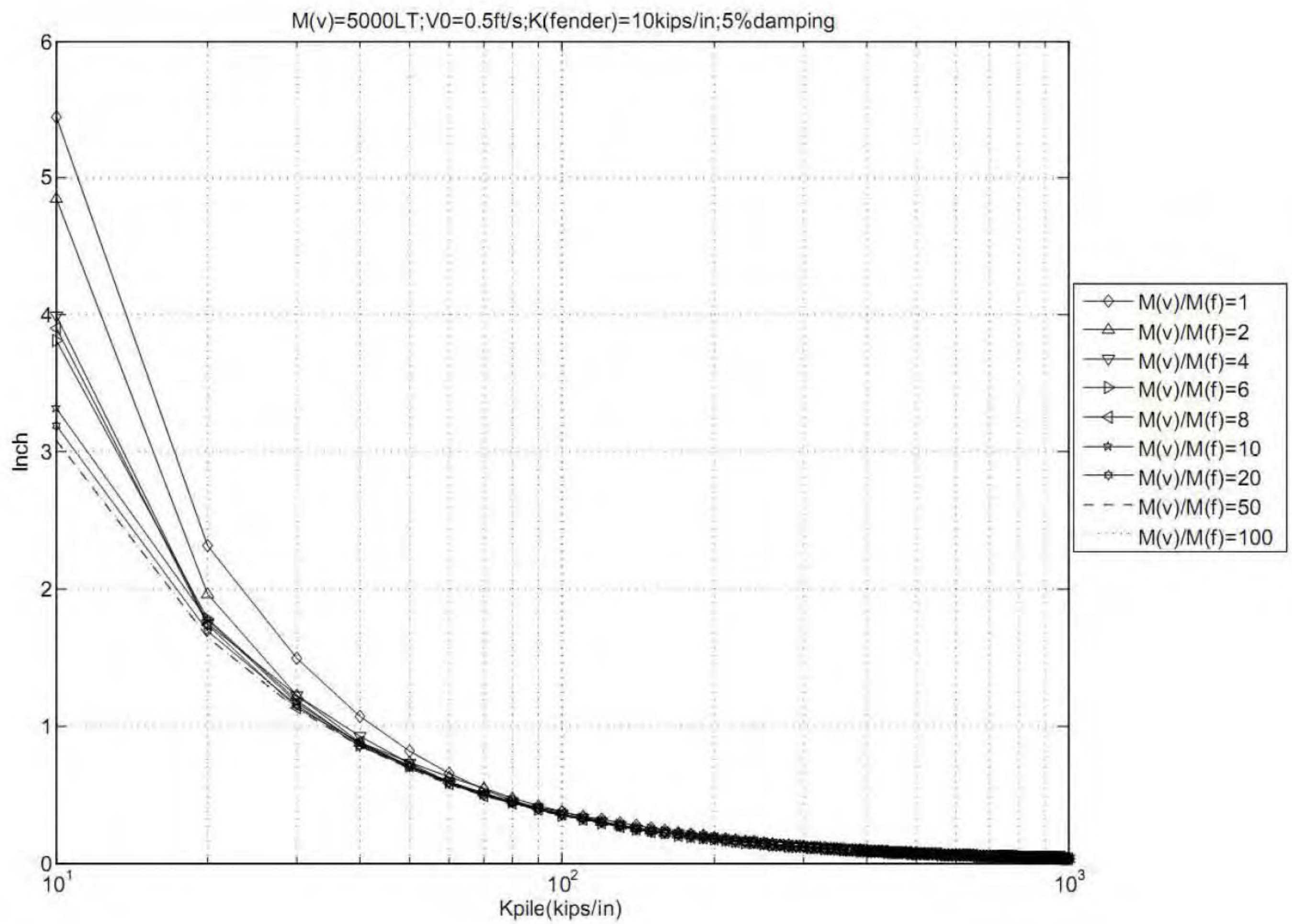


Fig. A.178 Displacement of the Piling System 2D-13b

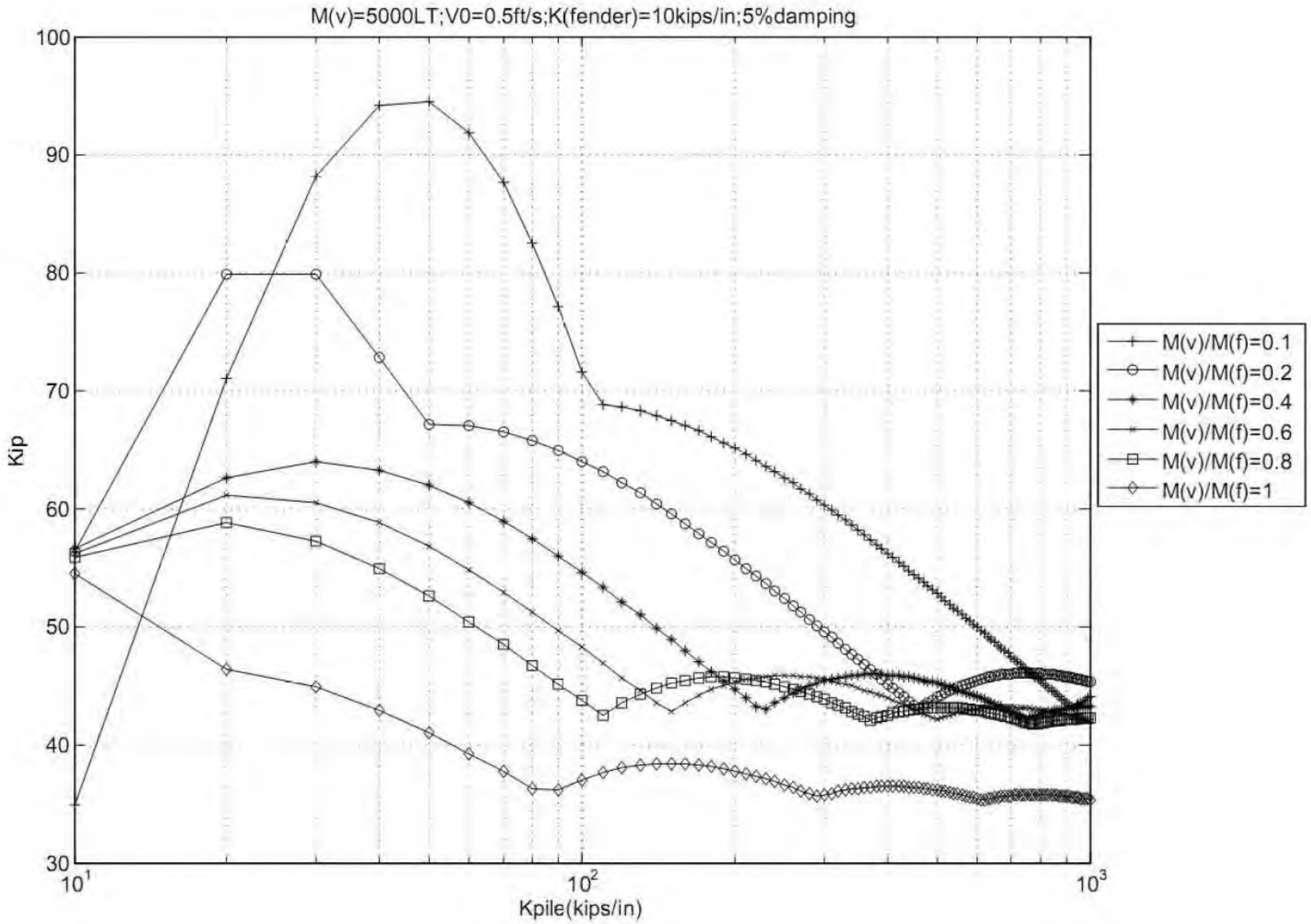


Fig. A.179 Reaction Force of the Piling System 2D-13a

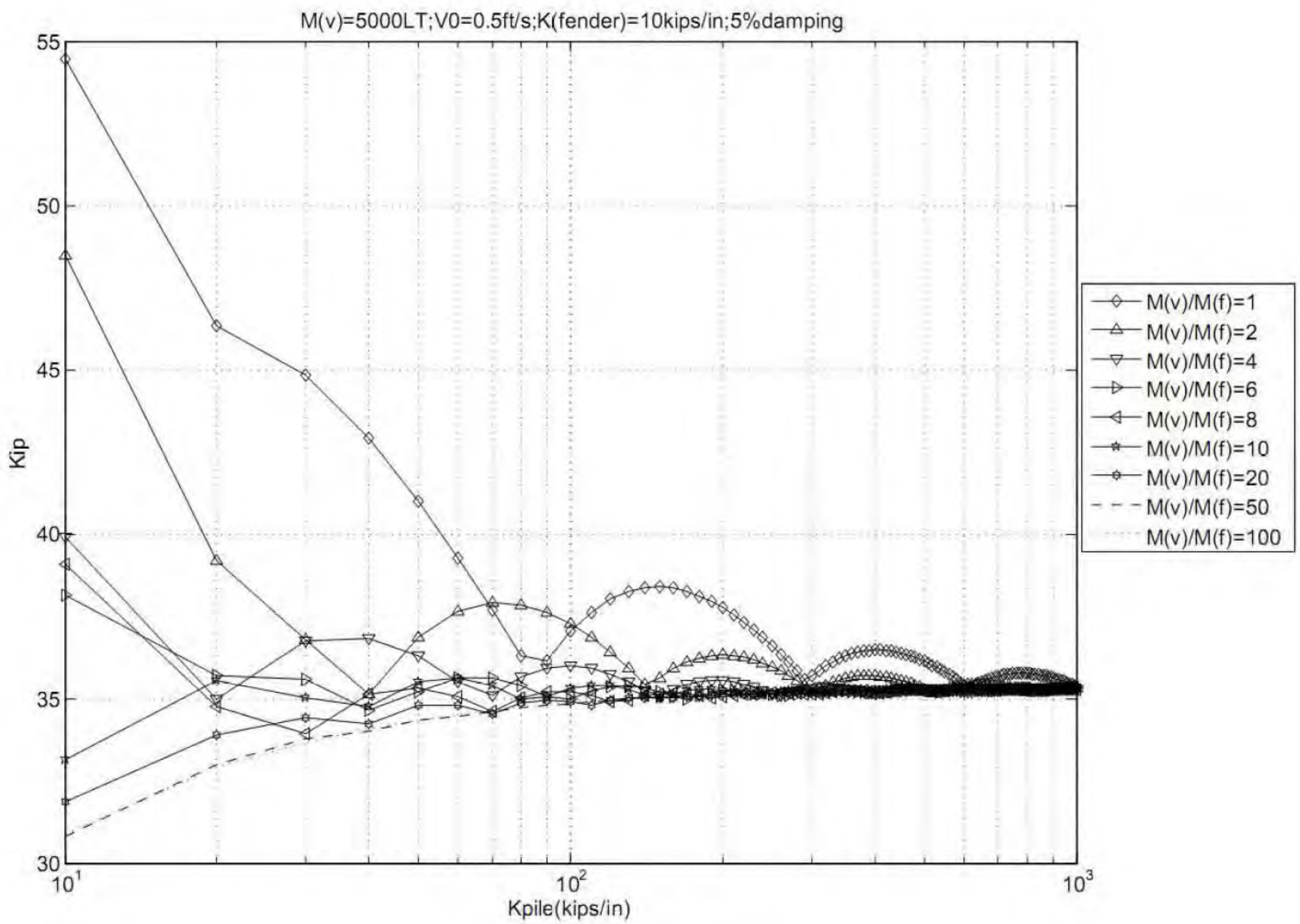


Fig. A.180 Reaction Force of the Piling System 2D-13b

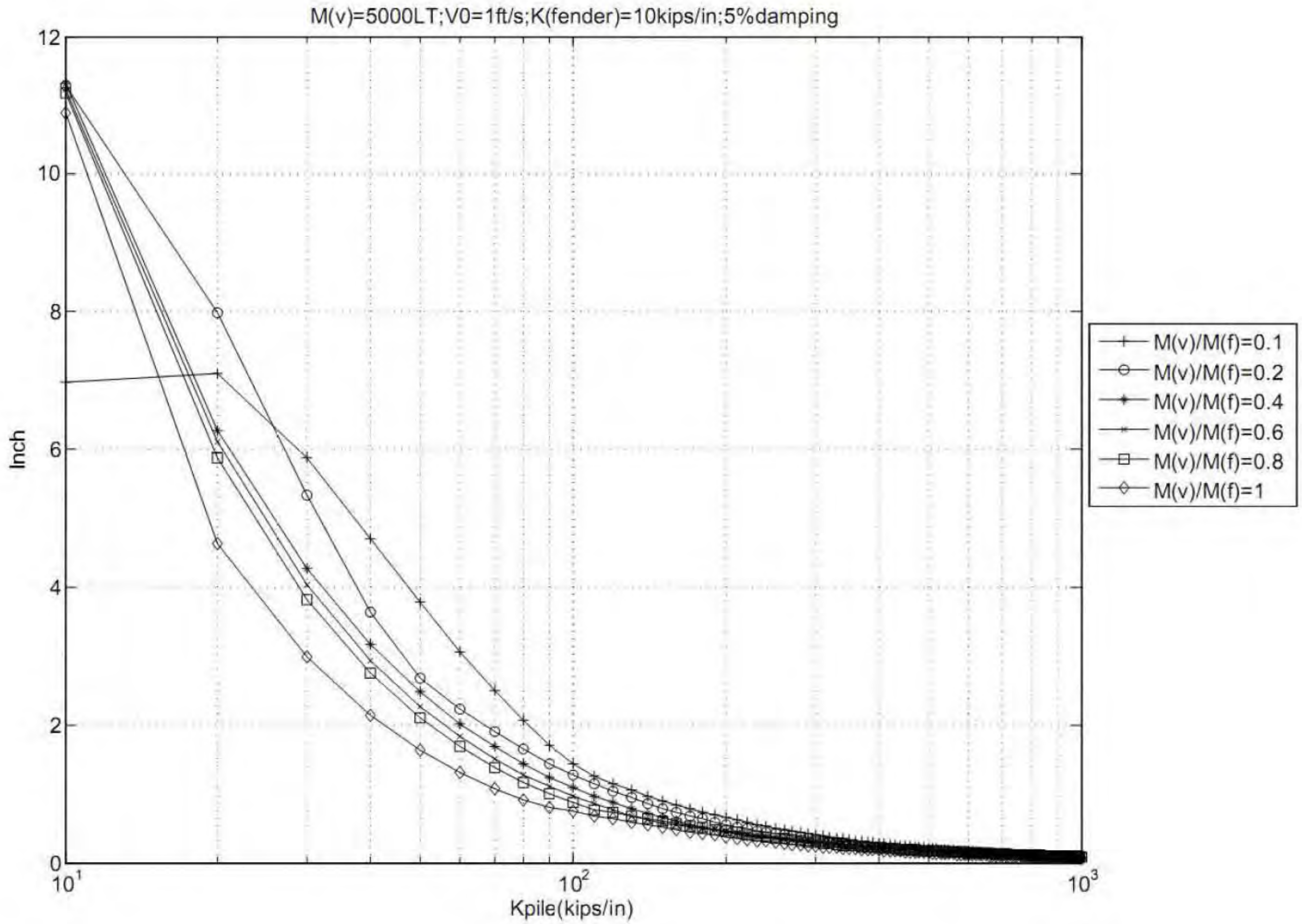


Fig. A.181 Displacement of the Piling System 2D-14a

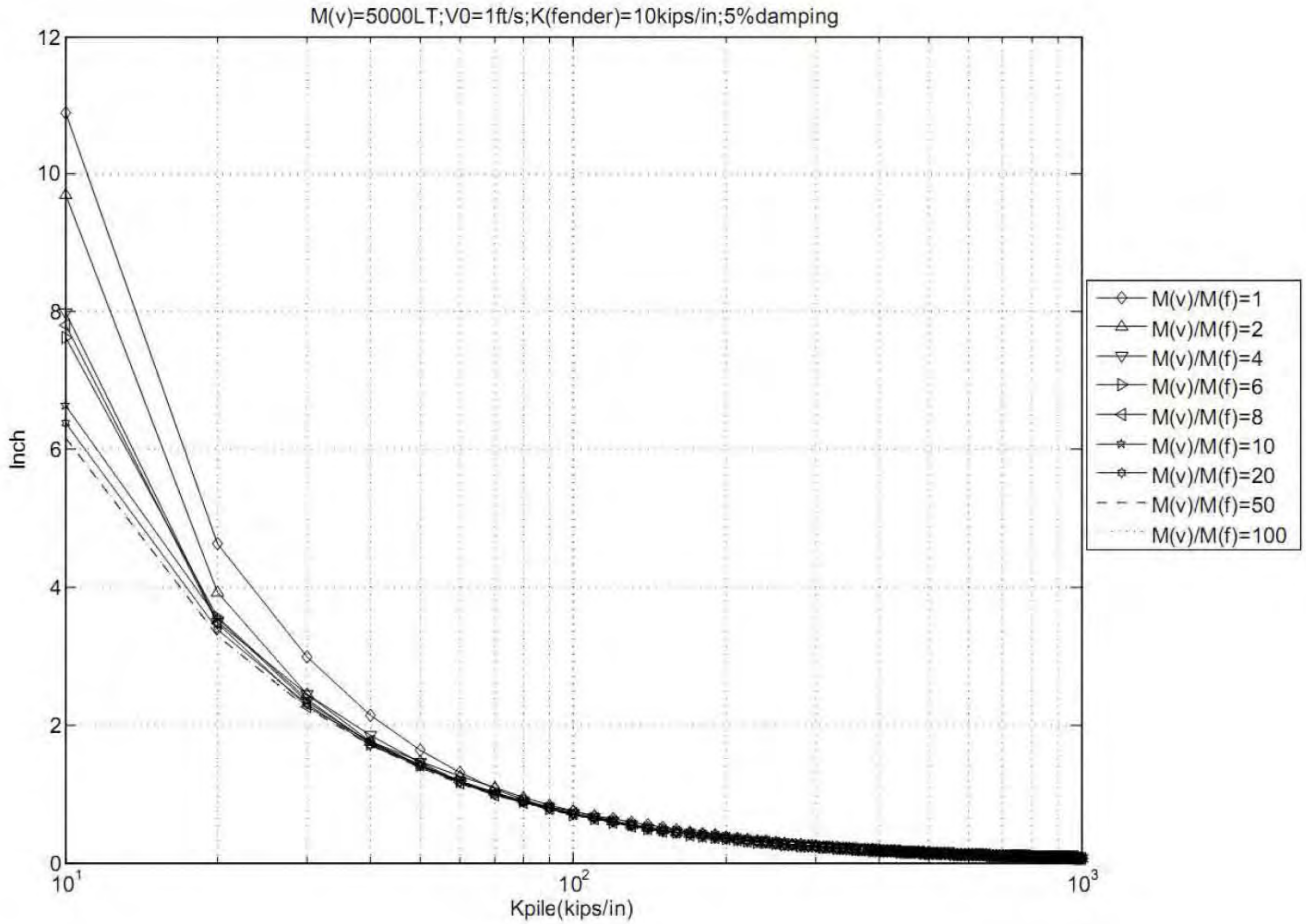


Fig. A.182 Displacement of the Piling System 2D-14b

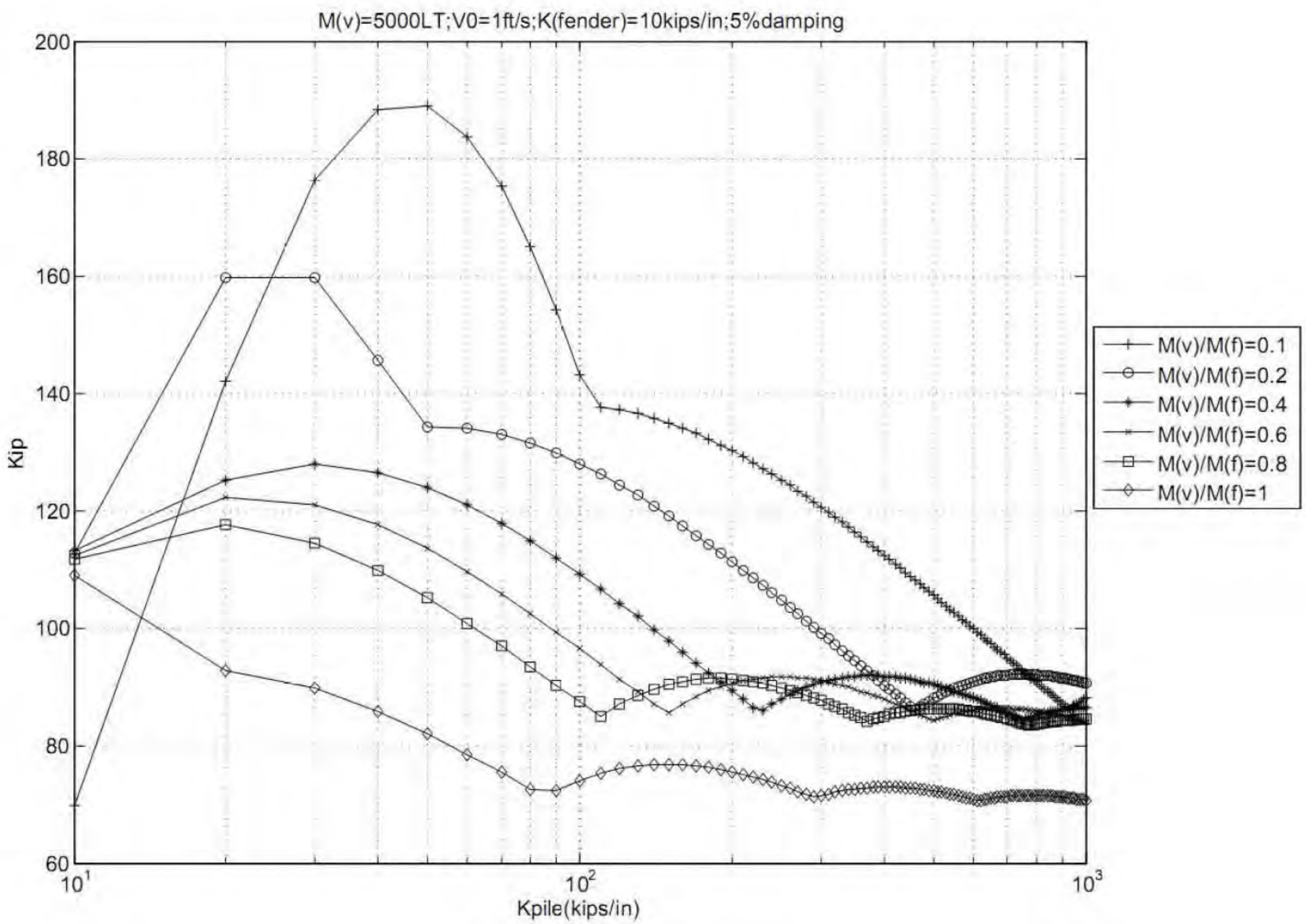


Fig. A.183 Reaction Force of the Piling System 2D-14a

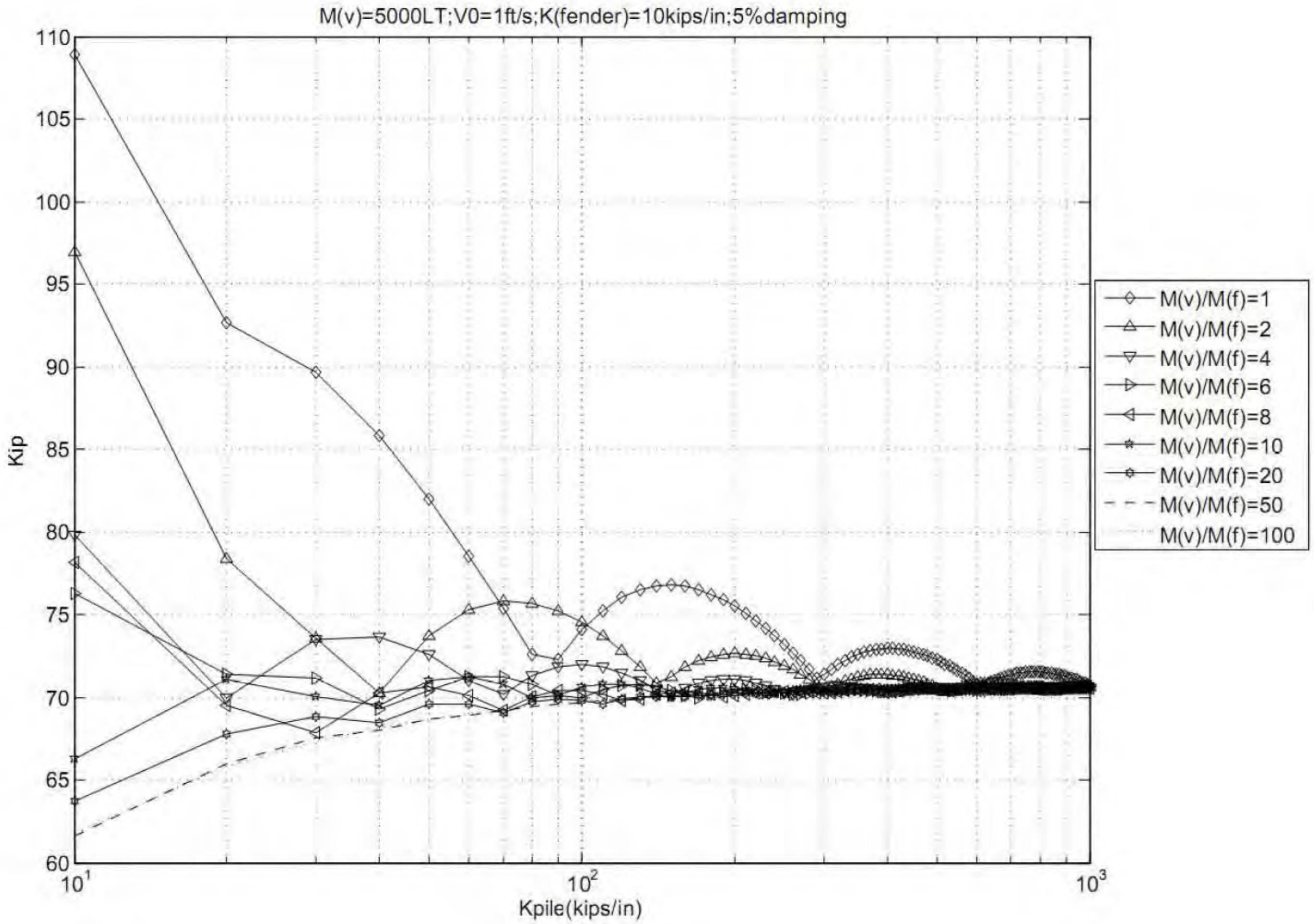


Fig. A.184 Reaction Force of the Piling System 2D-14b

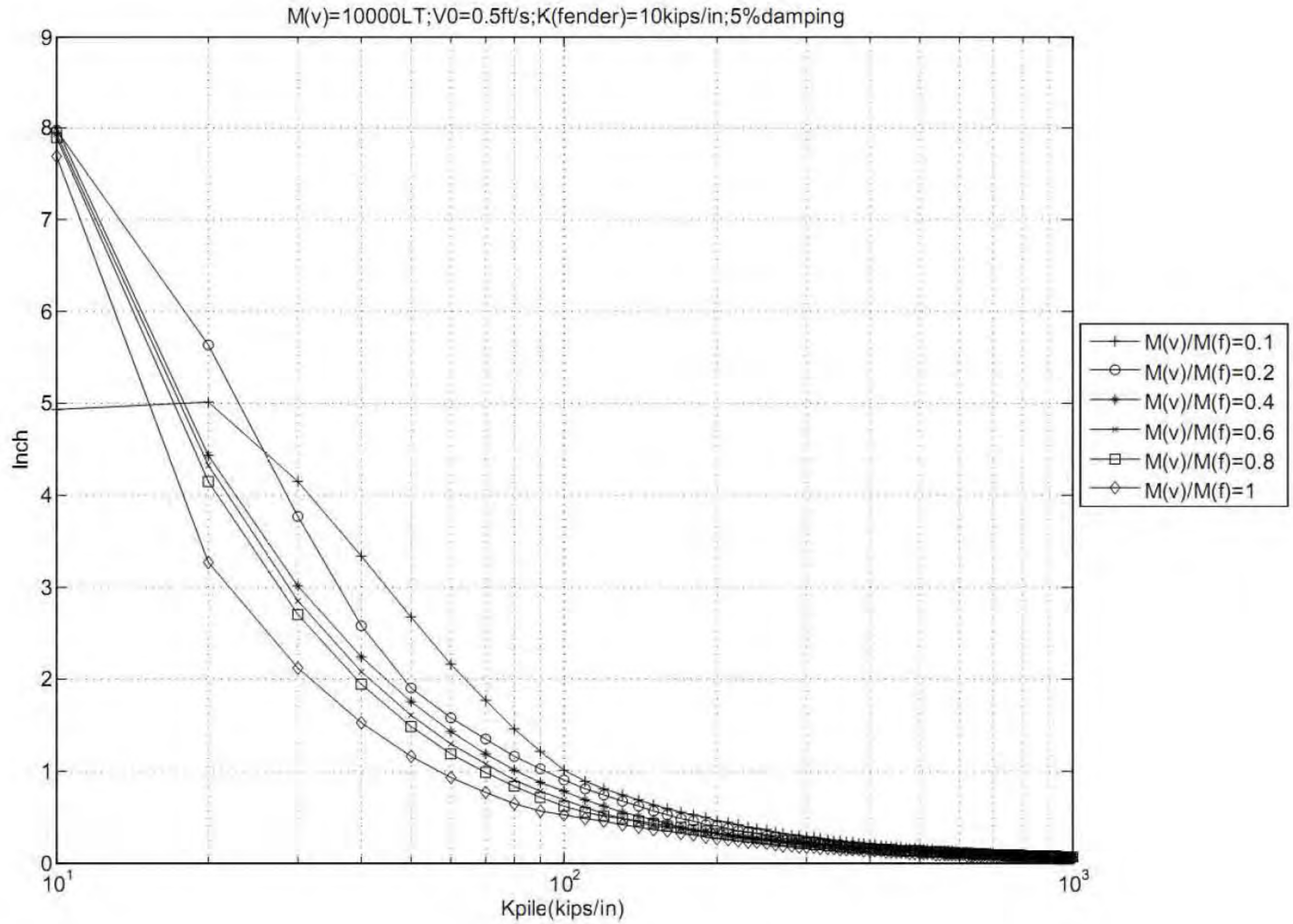


Fig. A.185 Displacement of the Piling System 2D-15a

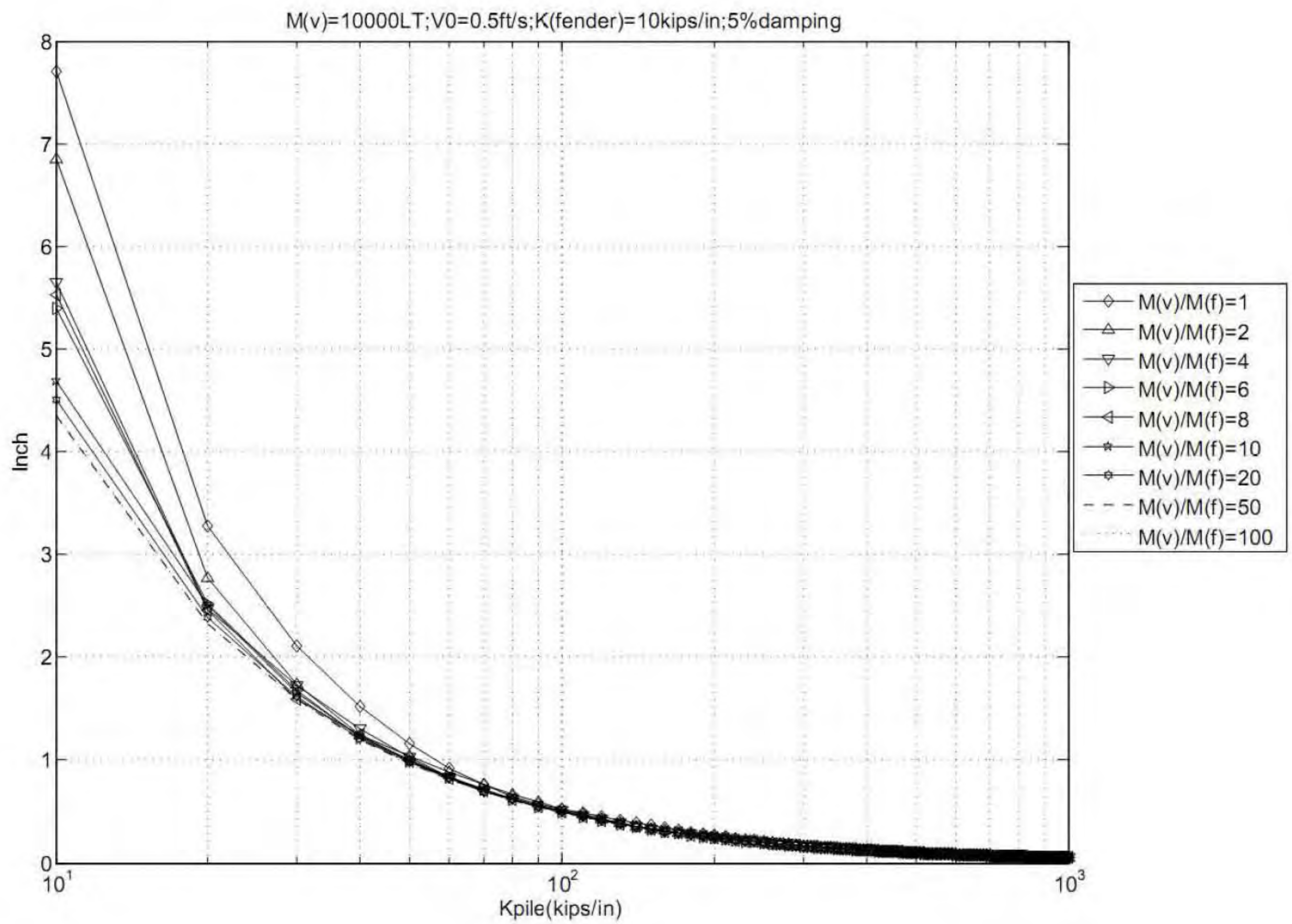


Fig. A.186 Displacement of the Piling System 2D-15b

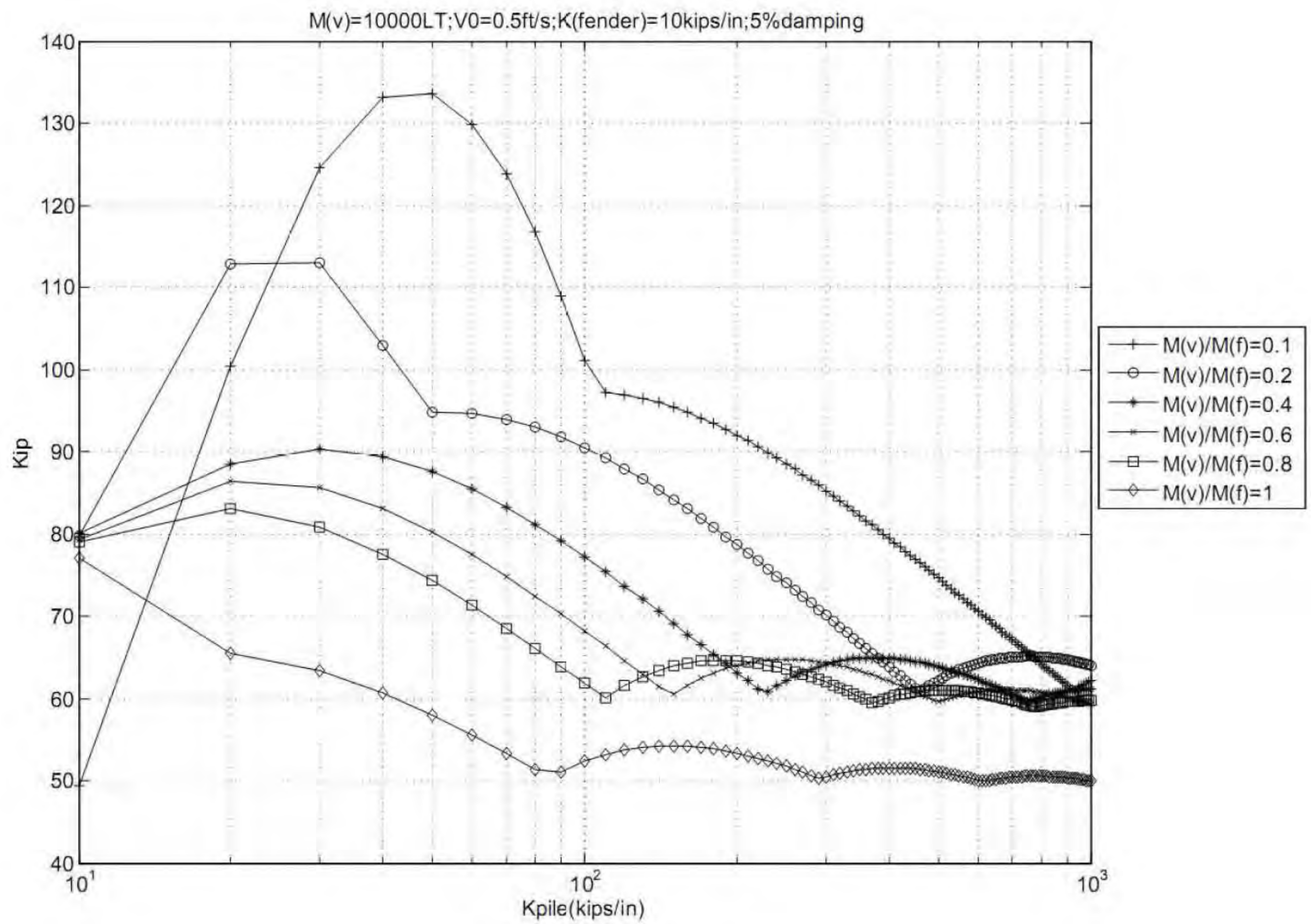


Fig. A.187 Reaction Force of the Piling System 2D-15a

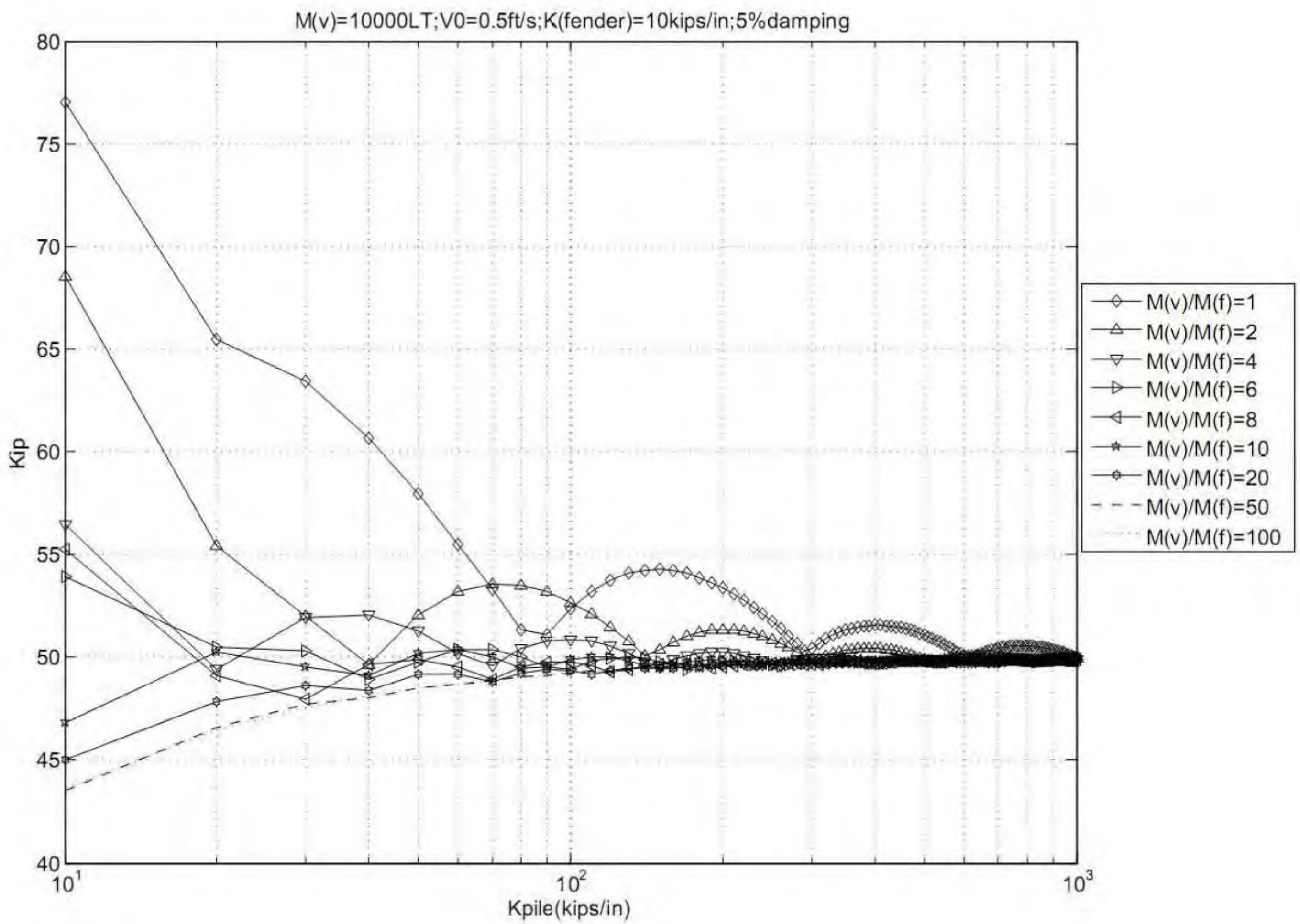


Fig. A.188 Reaction Force of the Piling System 2D-15b

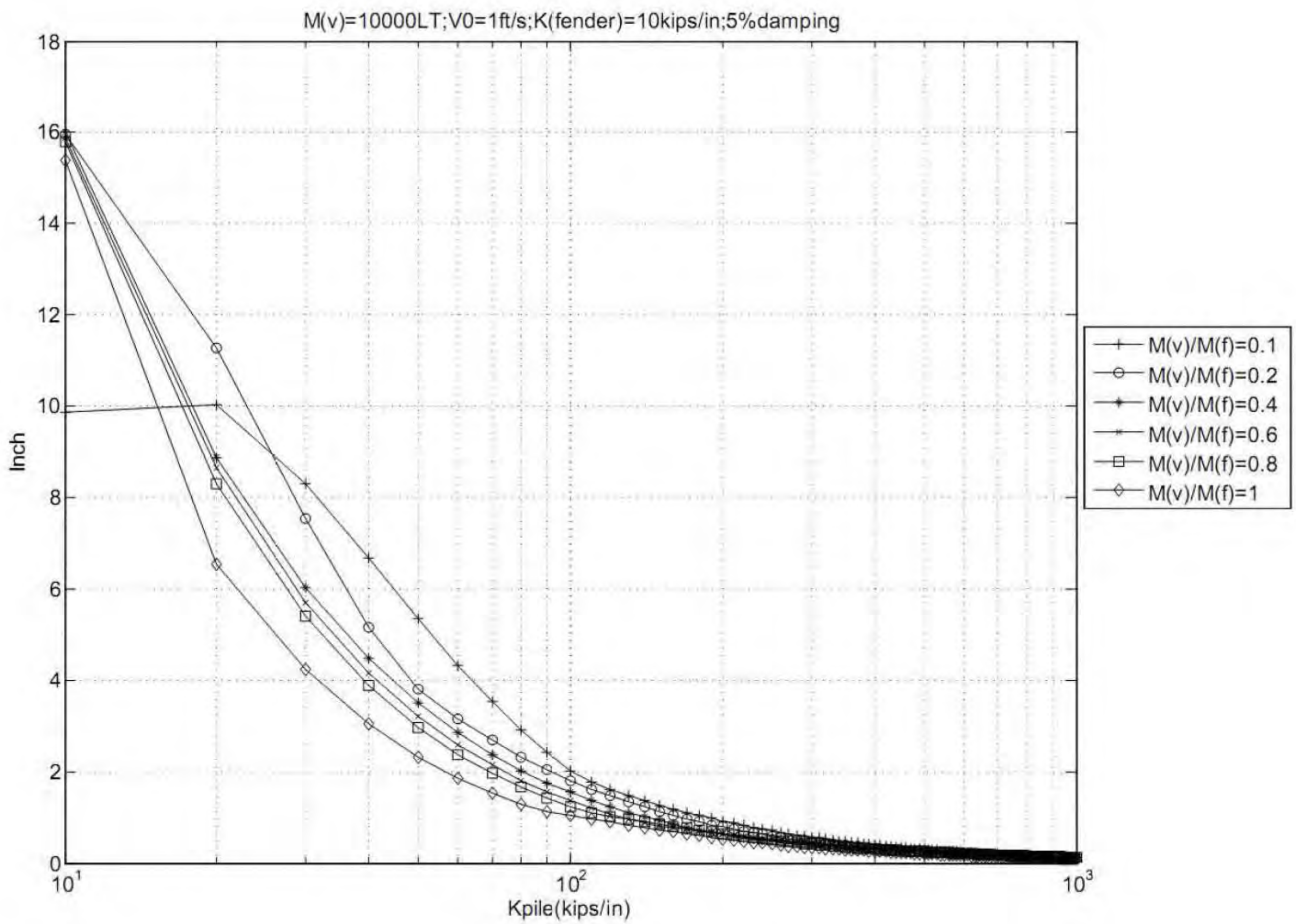


Fig. A.189 Displacement of the Piling System 2D-16a

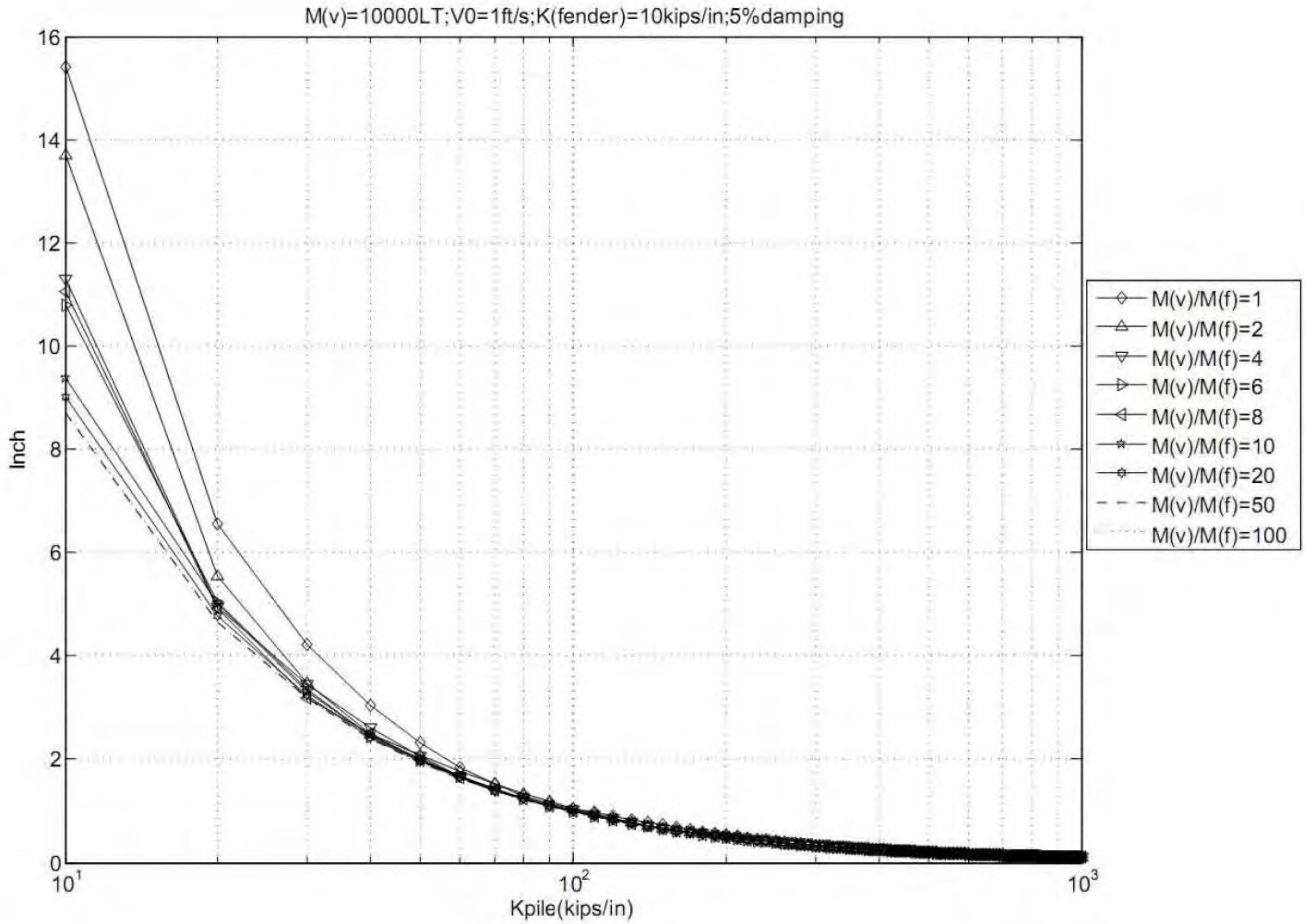


Fig. A.190 Displacement of the Piling System 2D-16b

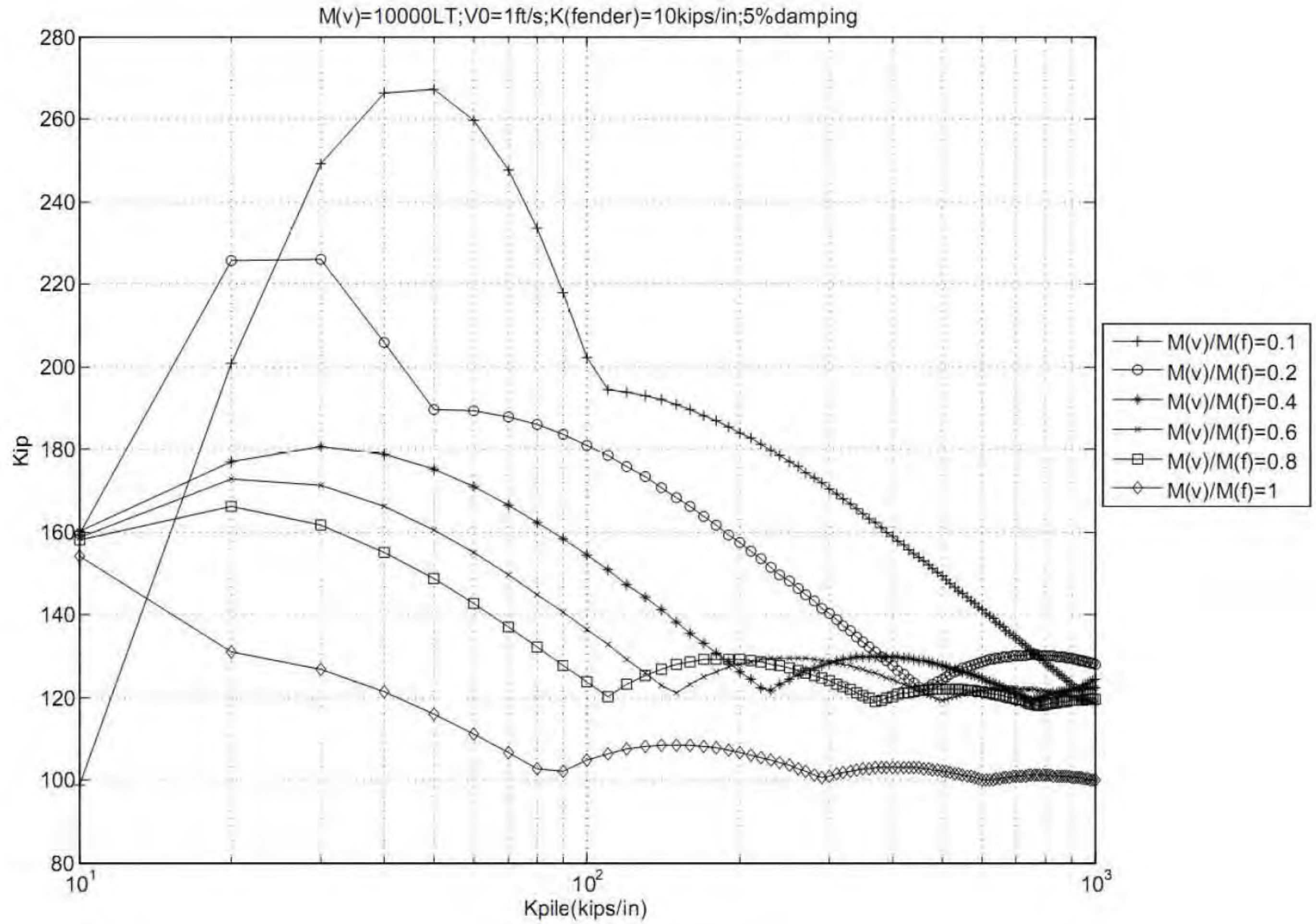


Fig. A.191 Reaction Force of the Piling System 2D-16a

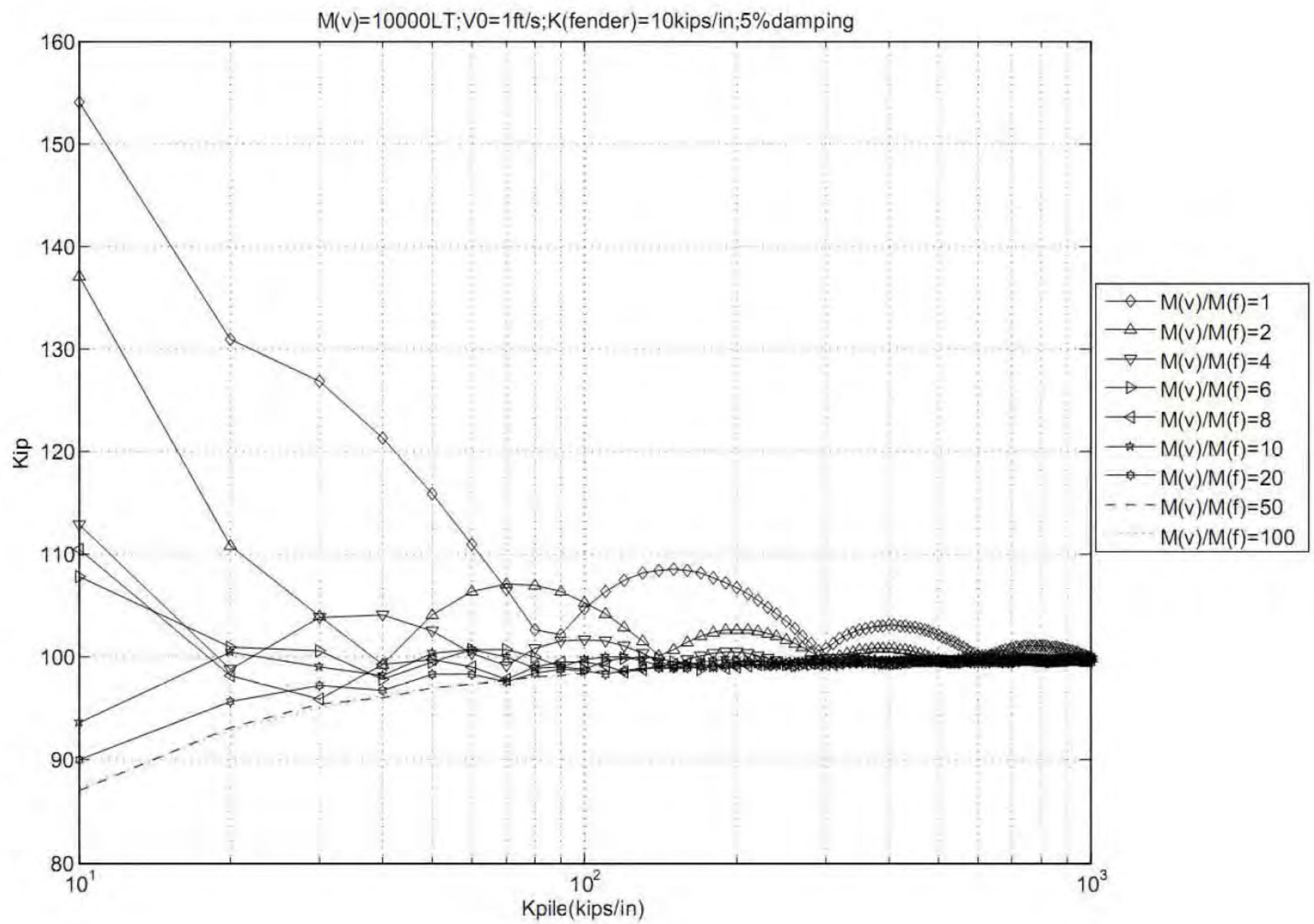


Fig. A.192 Reaction Force of the Piling System 2D-16b

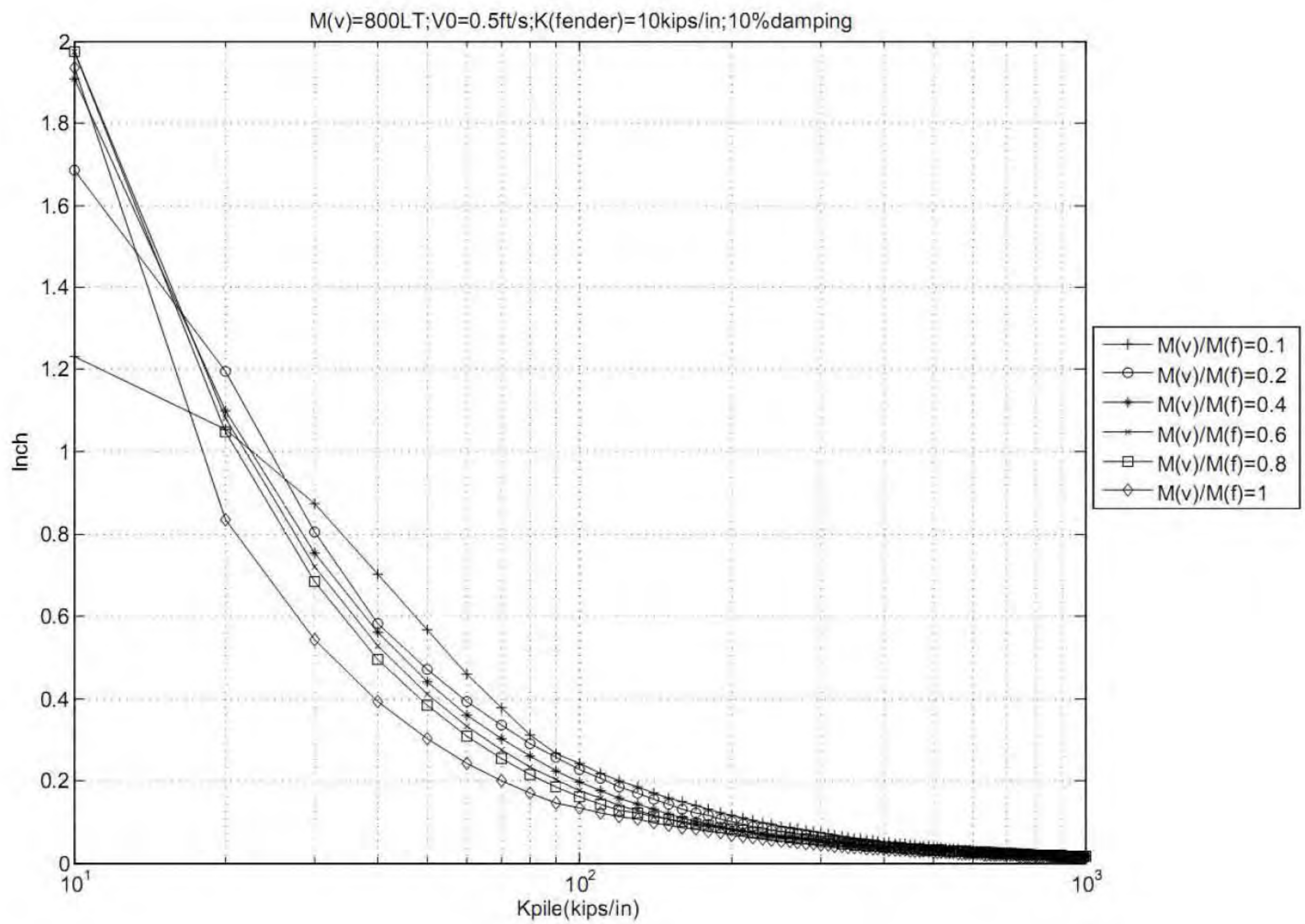


Fig. A.193 Displacement of the Piling System 2D-17a

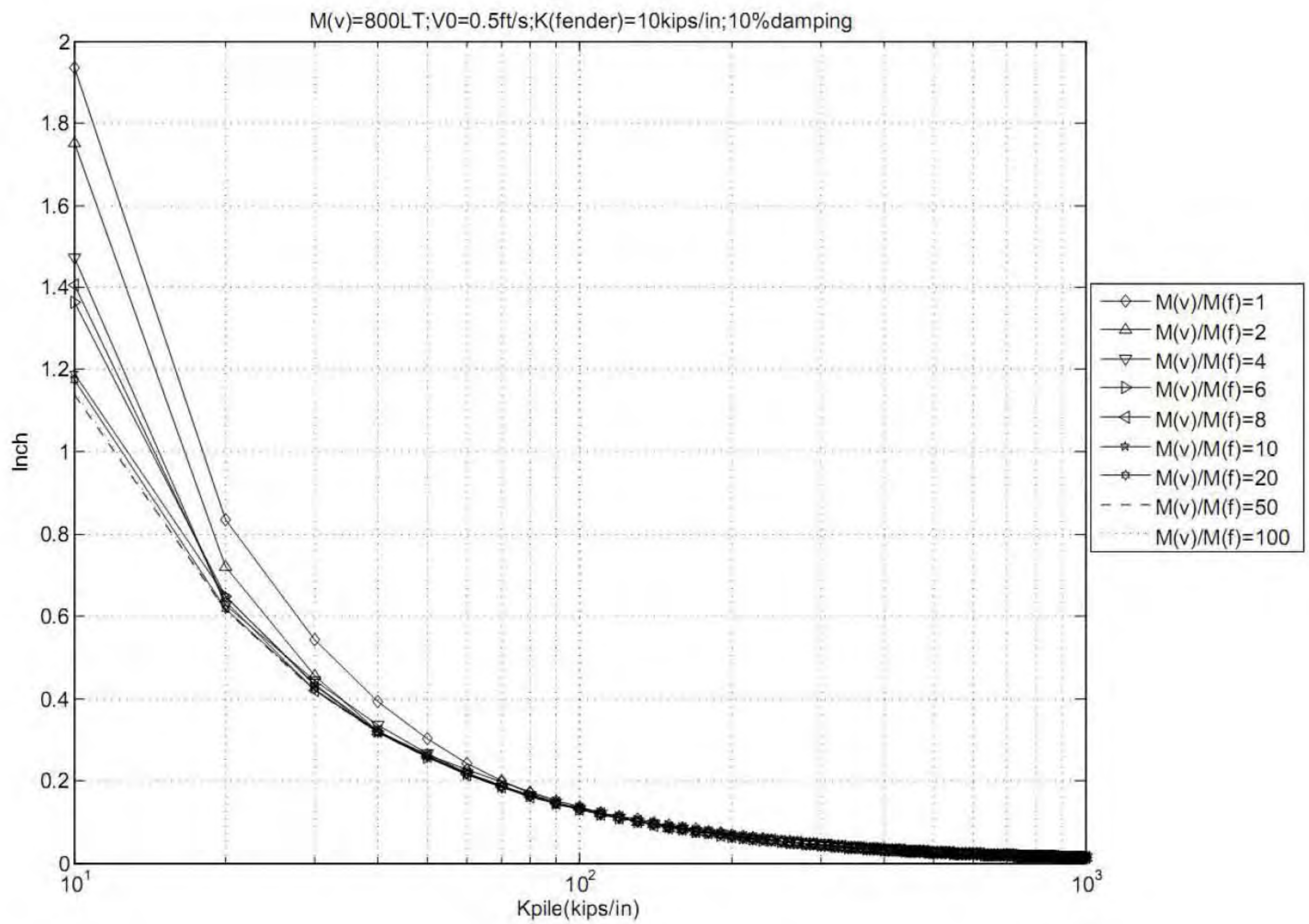


Fig. A.194 Displacement of the Piling System 2D-17b

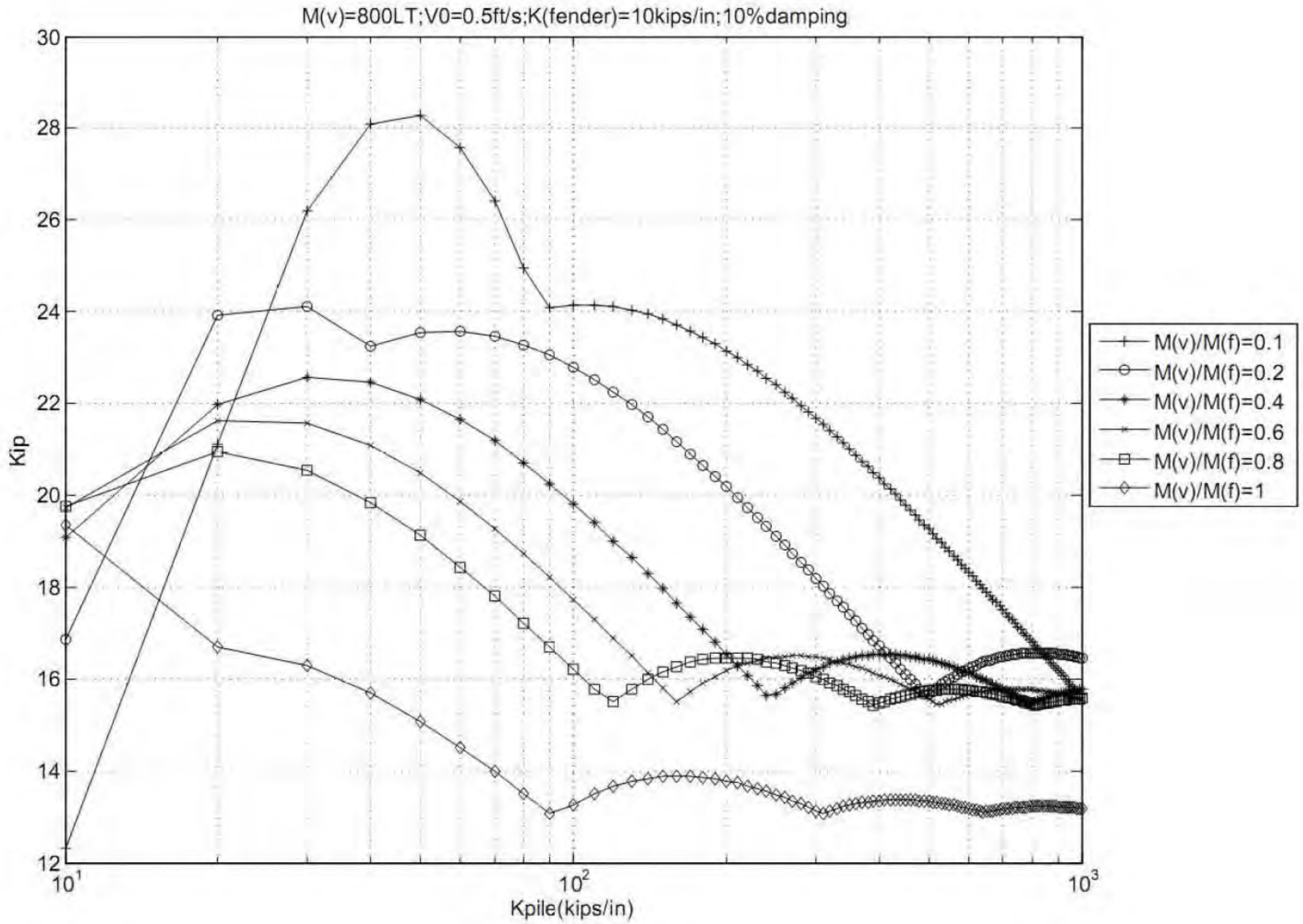


Fig. A.195 Reaction Force of the Piling System 2D-17a

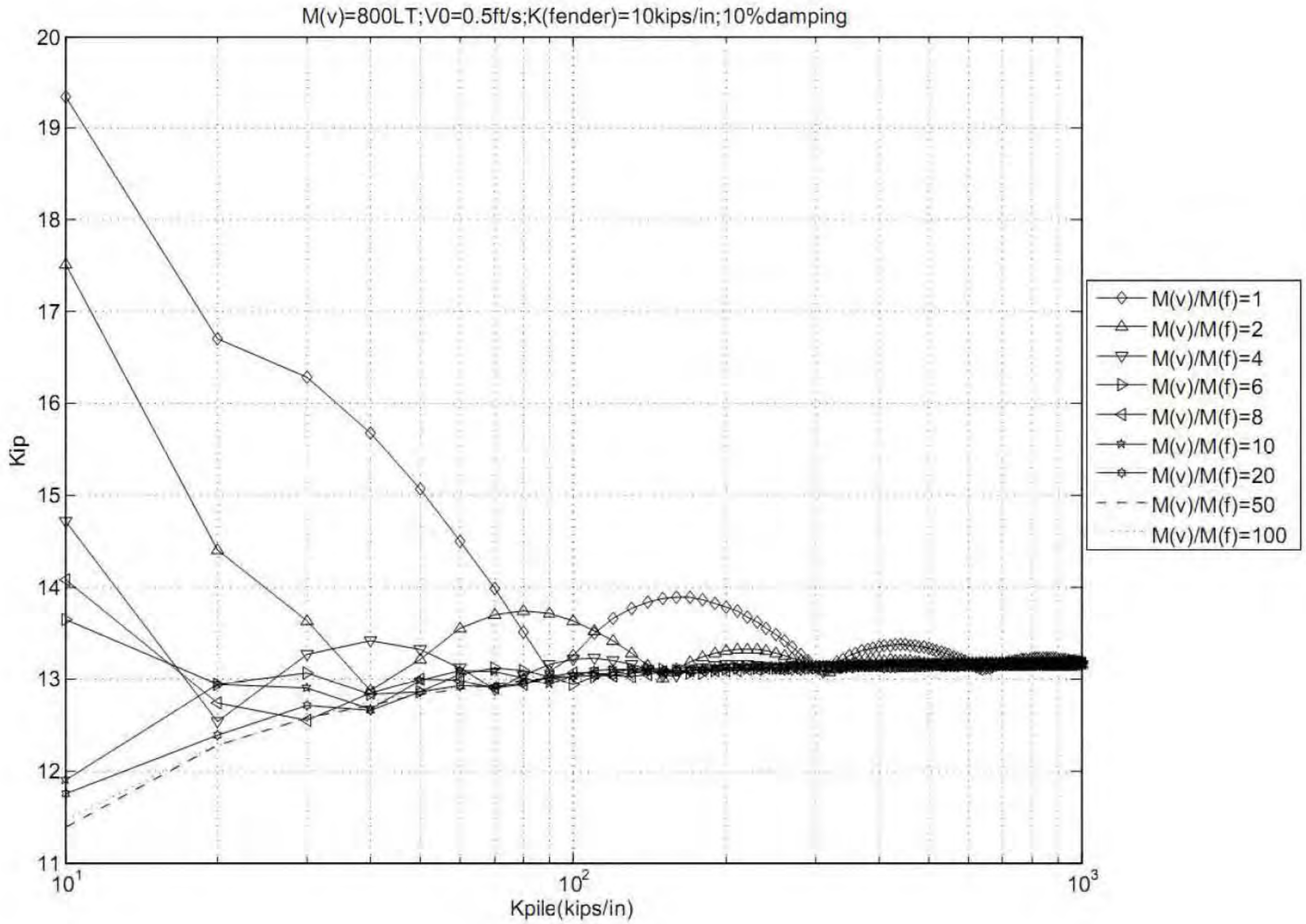


Fig. A.196 Reaction Force of the Piling System 2D-17b

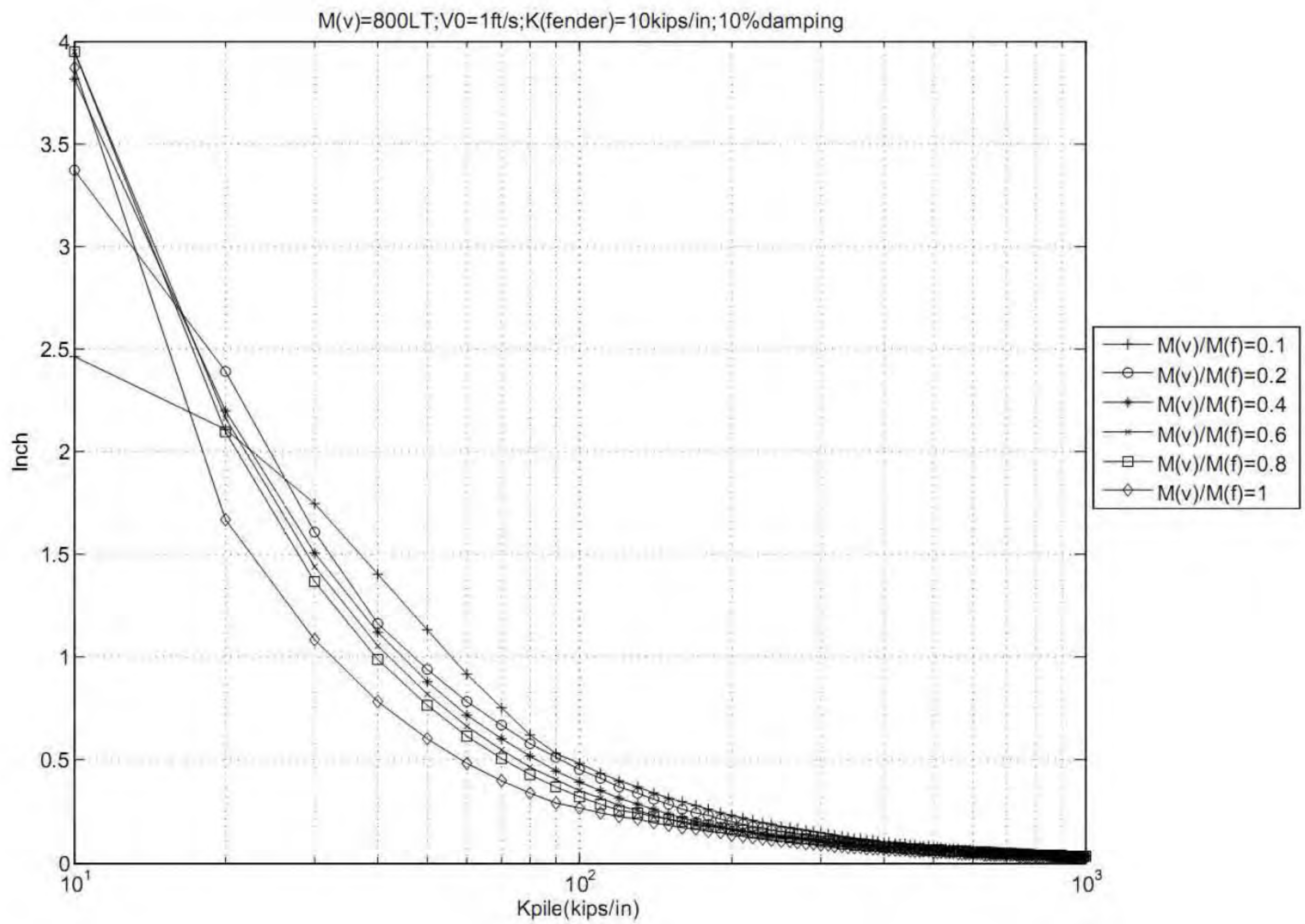


Fig. A.197 Displacement of the Piling System 2D-18a

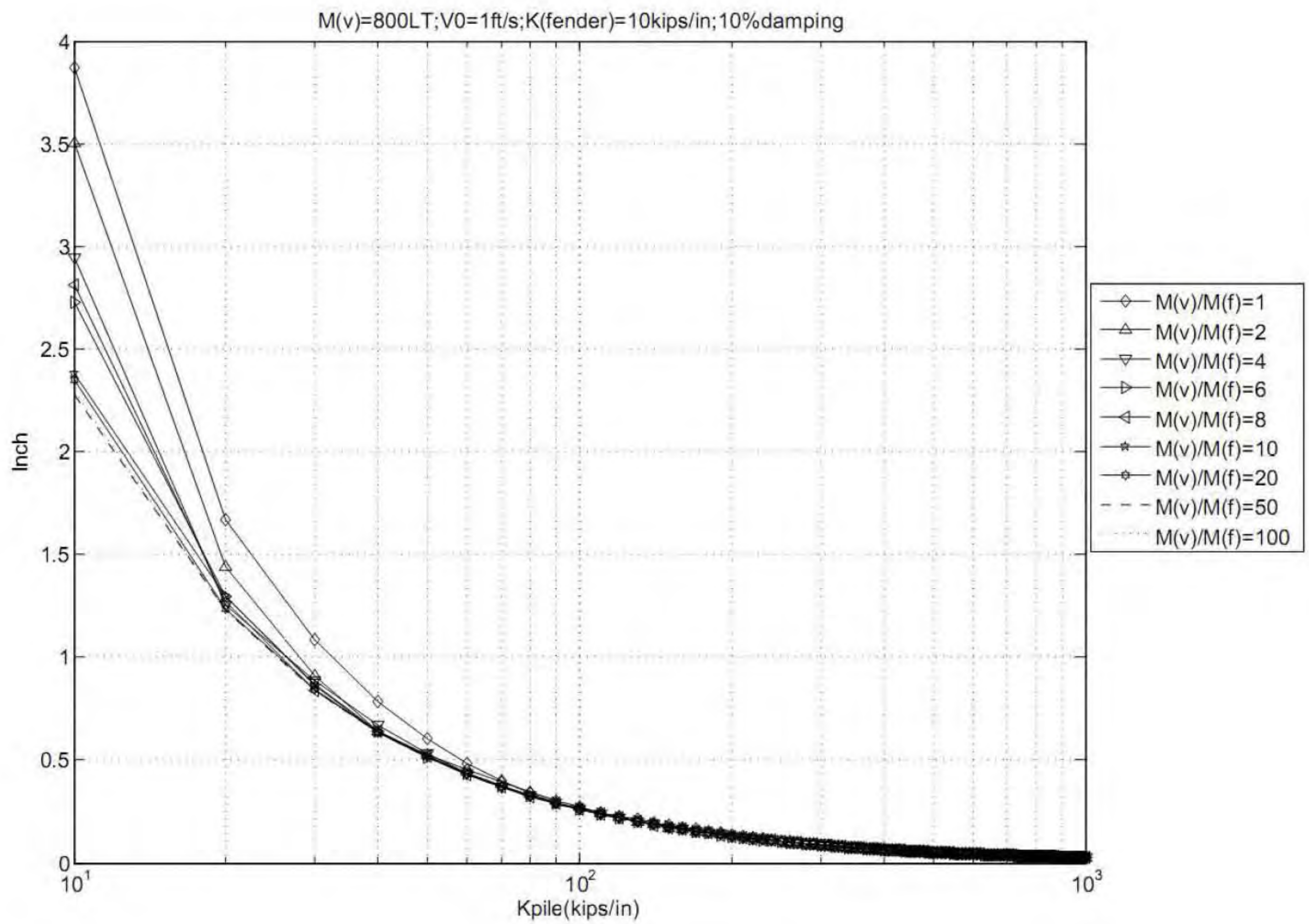


Fig. A.198 Displacement of the Piling System 2D-18b

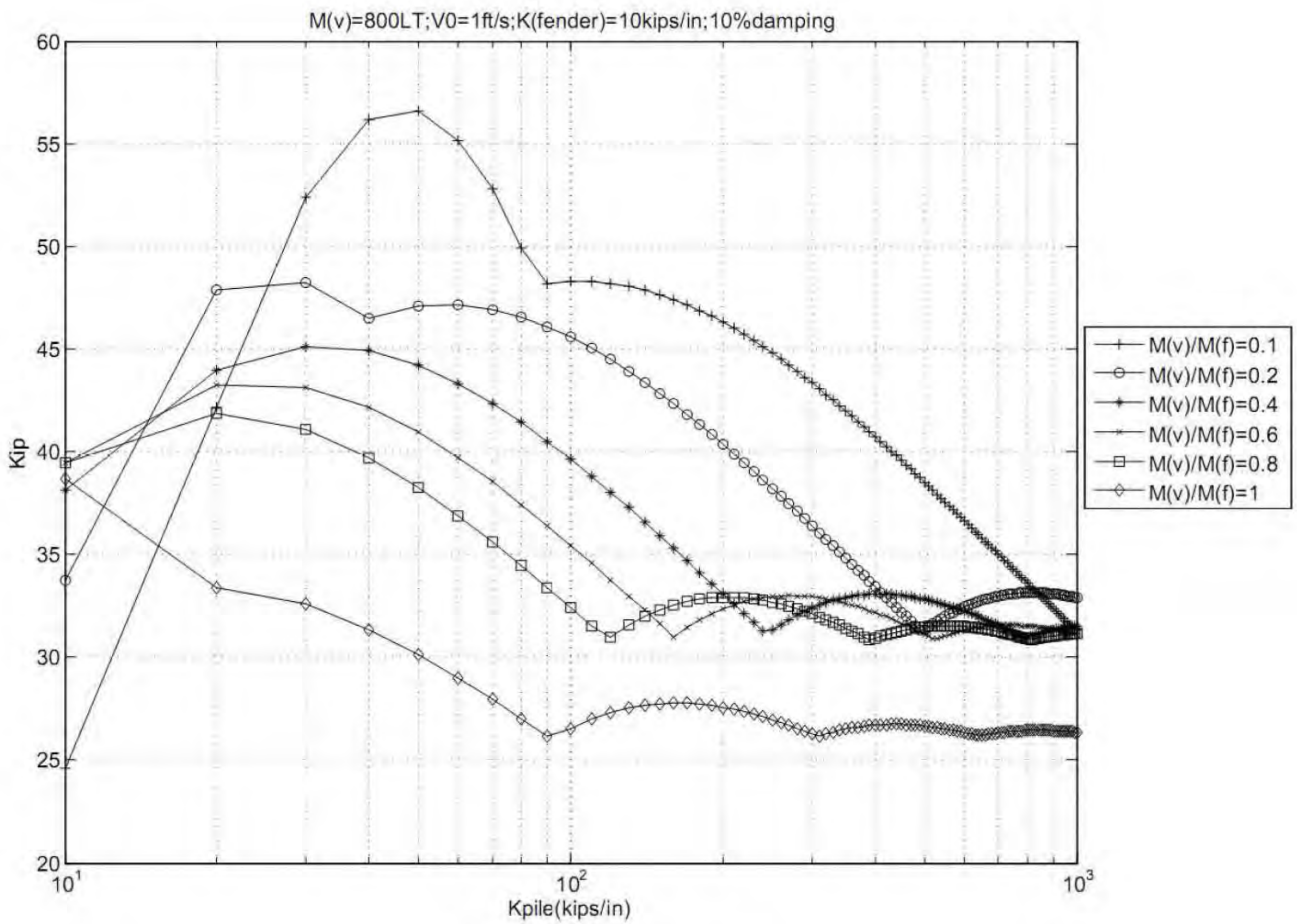


Fig. A.199 Reaction Force of the Piling System 2D-18a

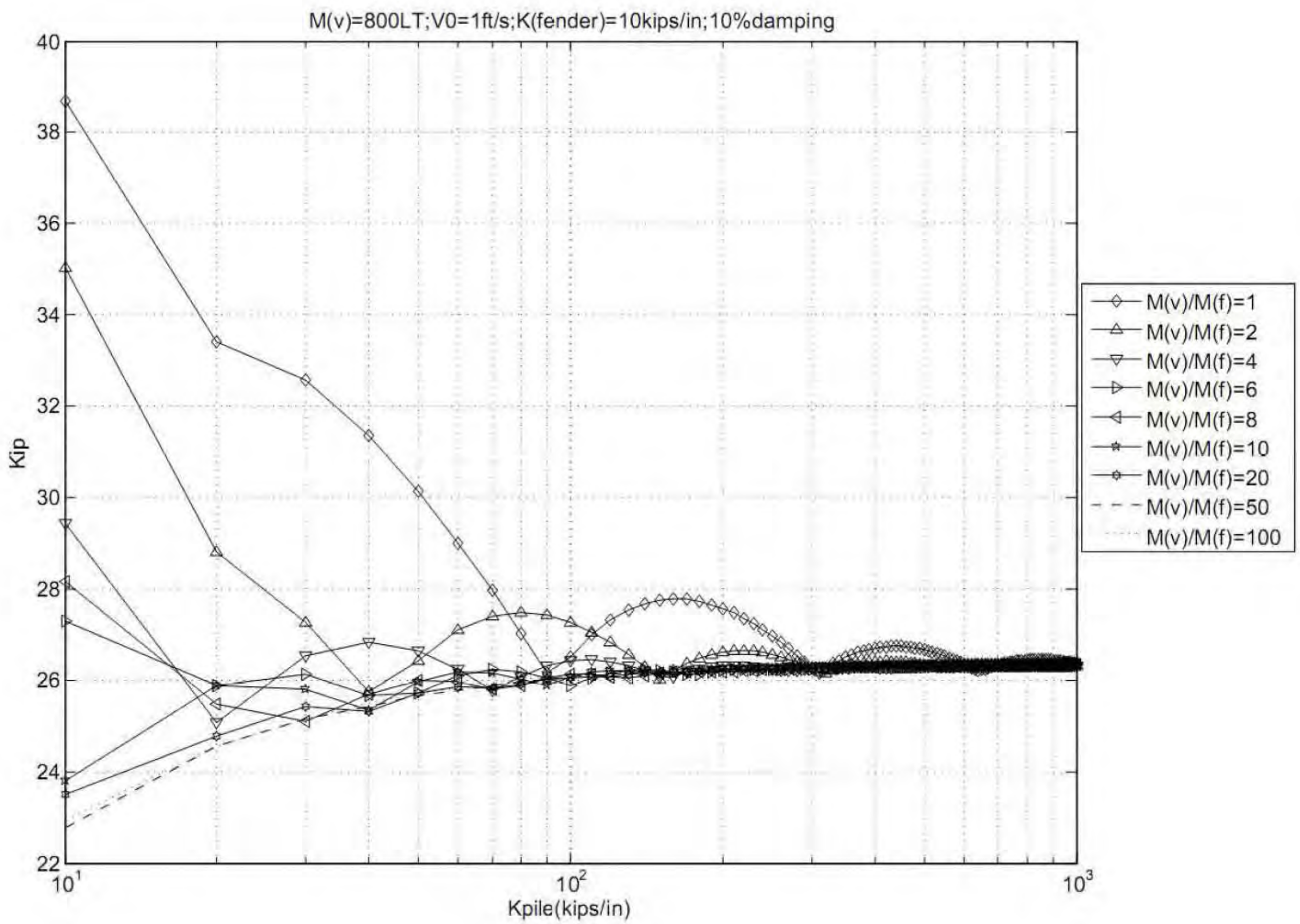


Fig. A.200 Reaction Force of the Piling System 2D-18b

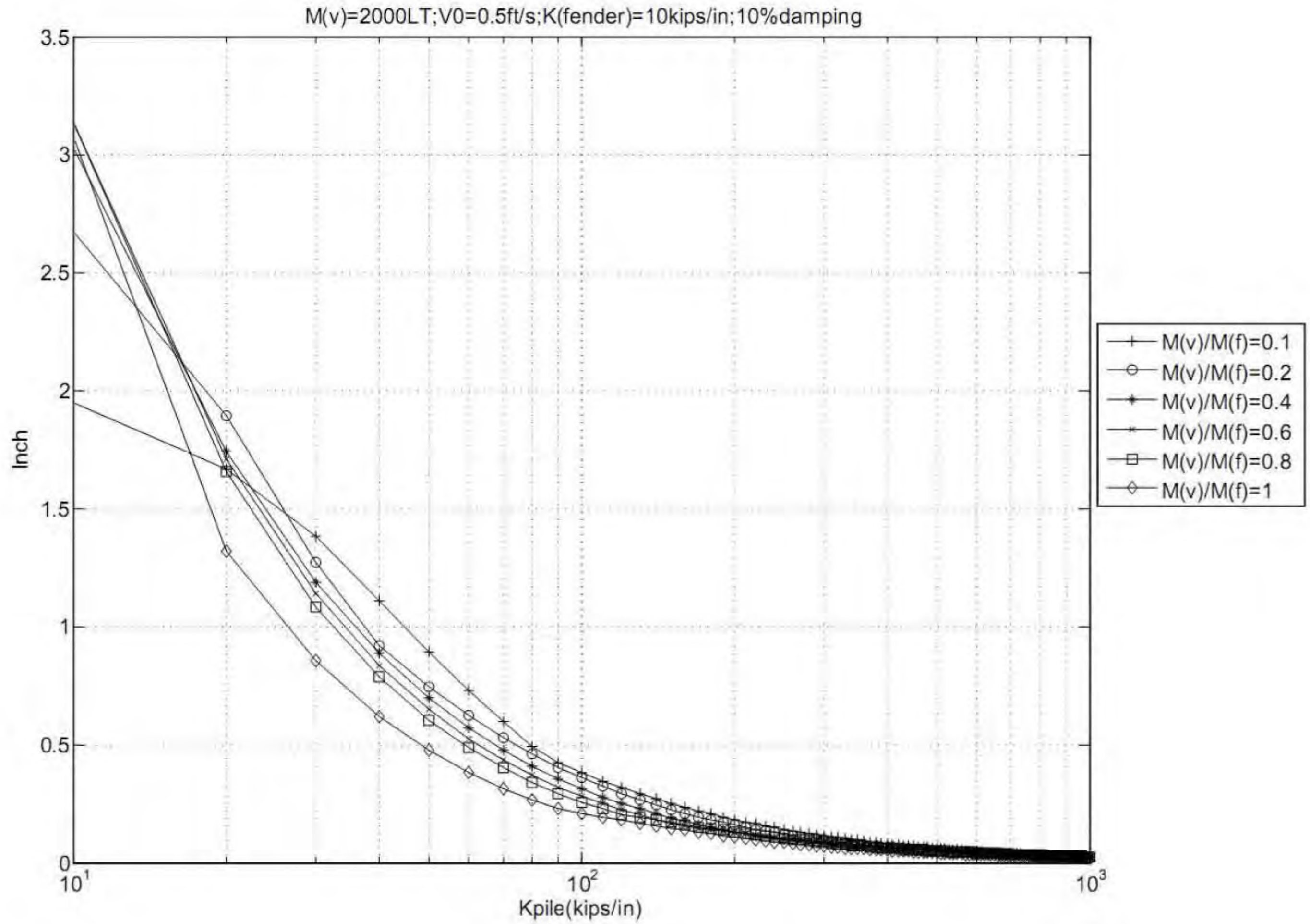


Fig. A.201 Displacement of the Piling System 2D-19a

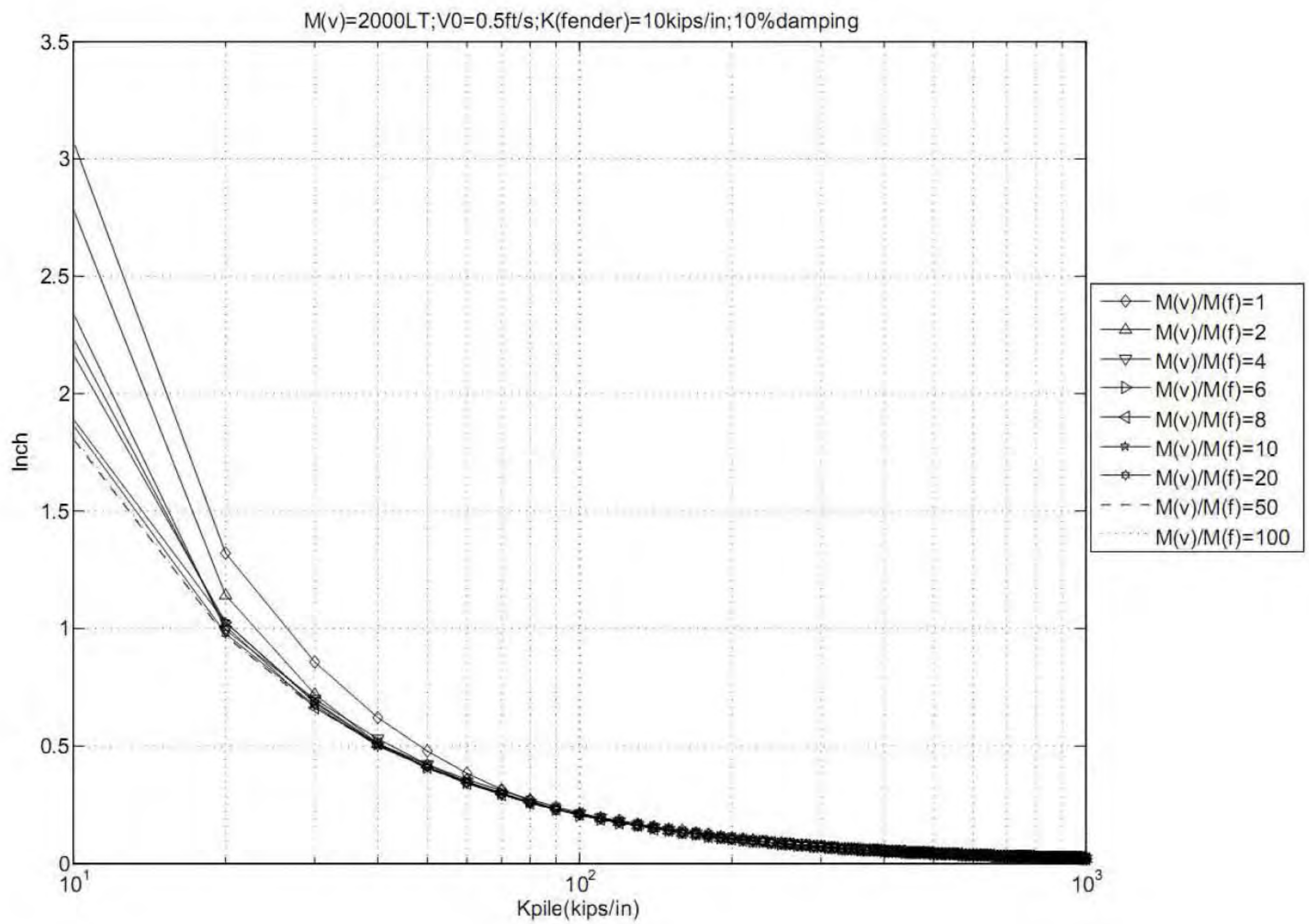


Fig. A.202 Displacement of the Piling System 2D-19b

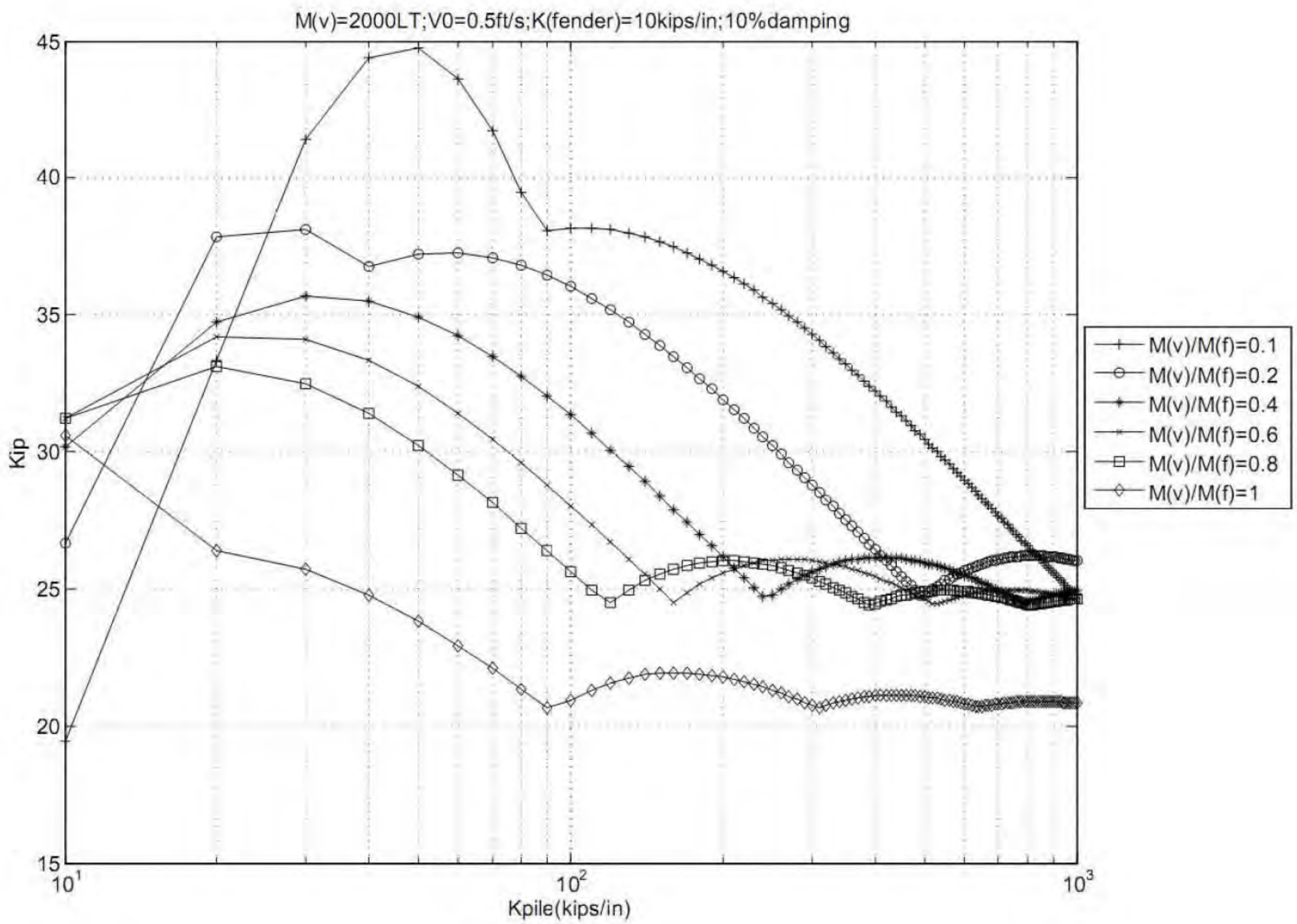


Fig. A.203 Reaction Force of the Piling System 2D-19a

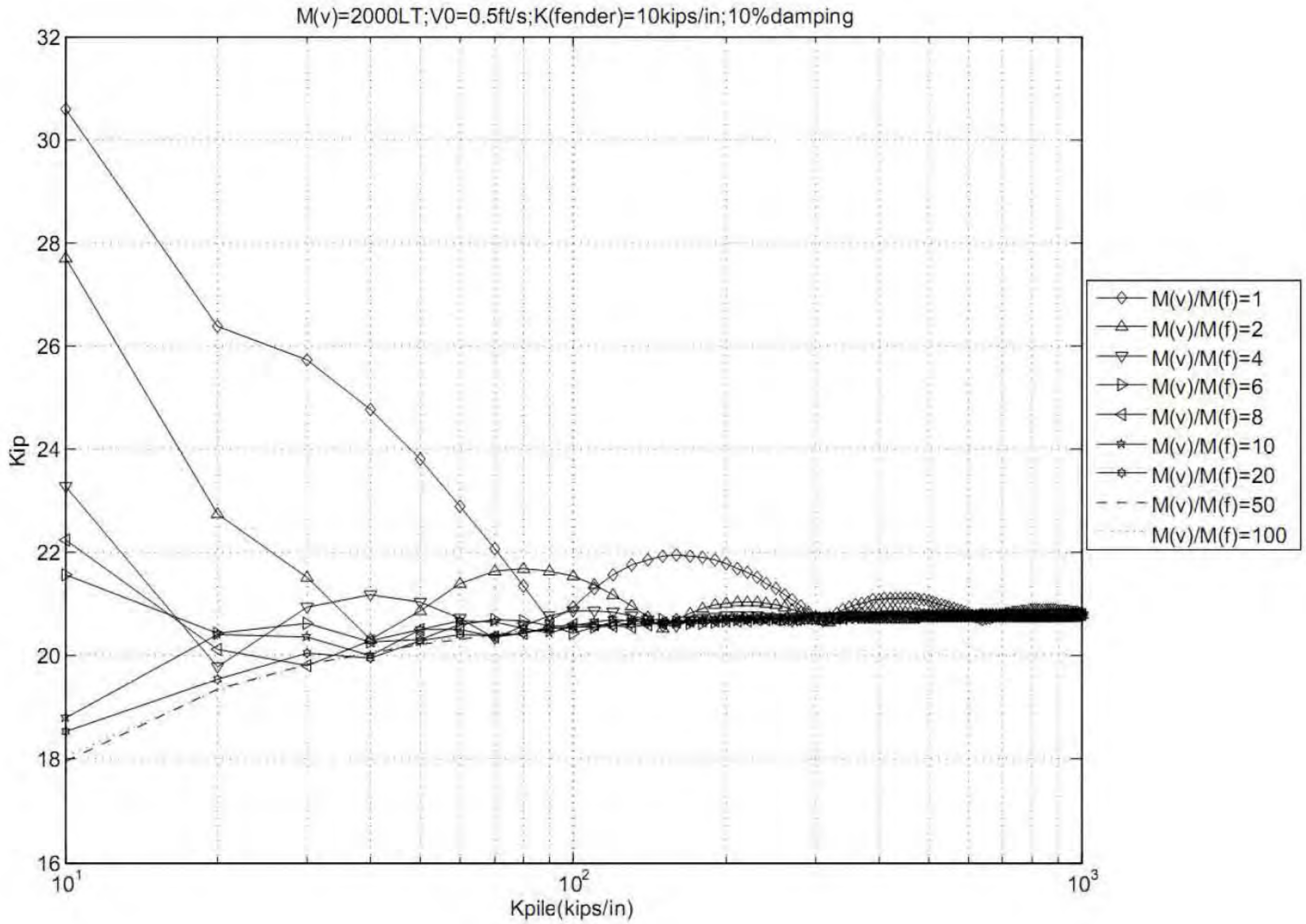


Fig. A.204 Reaction Force of the Piling System 2D-19b

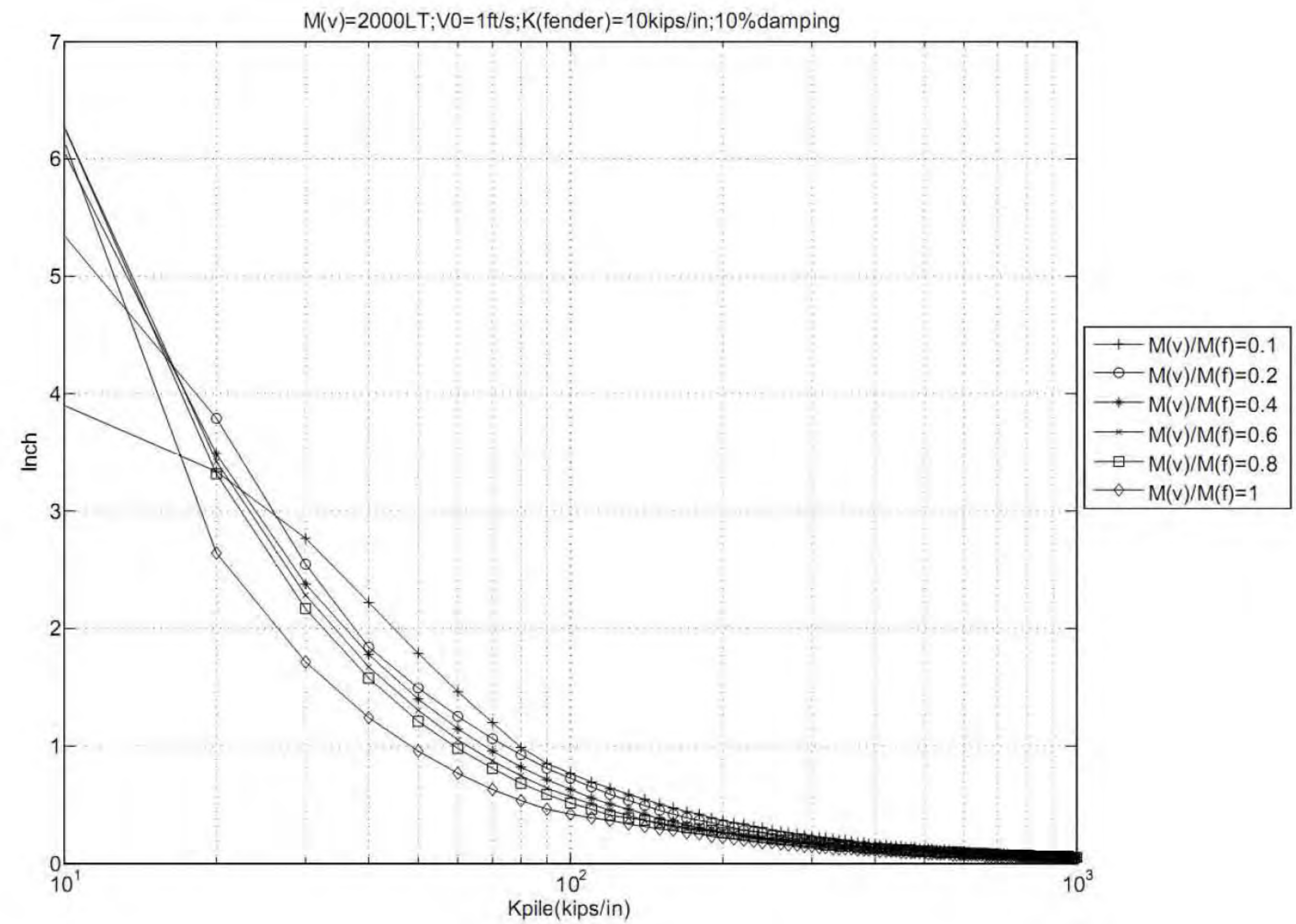


Fig. A.205 Displacement of the Piling System 2D-20a

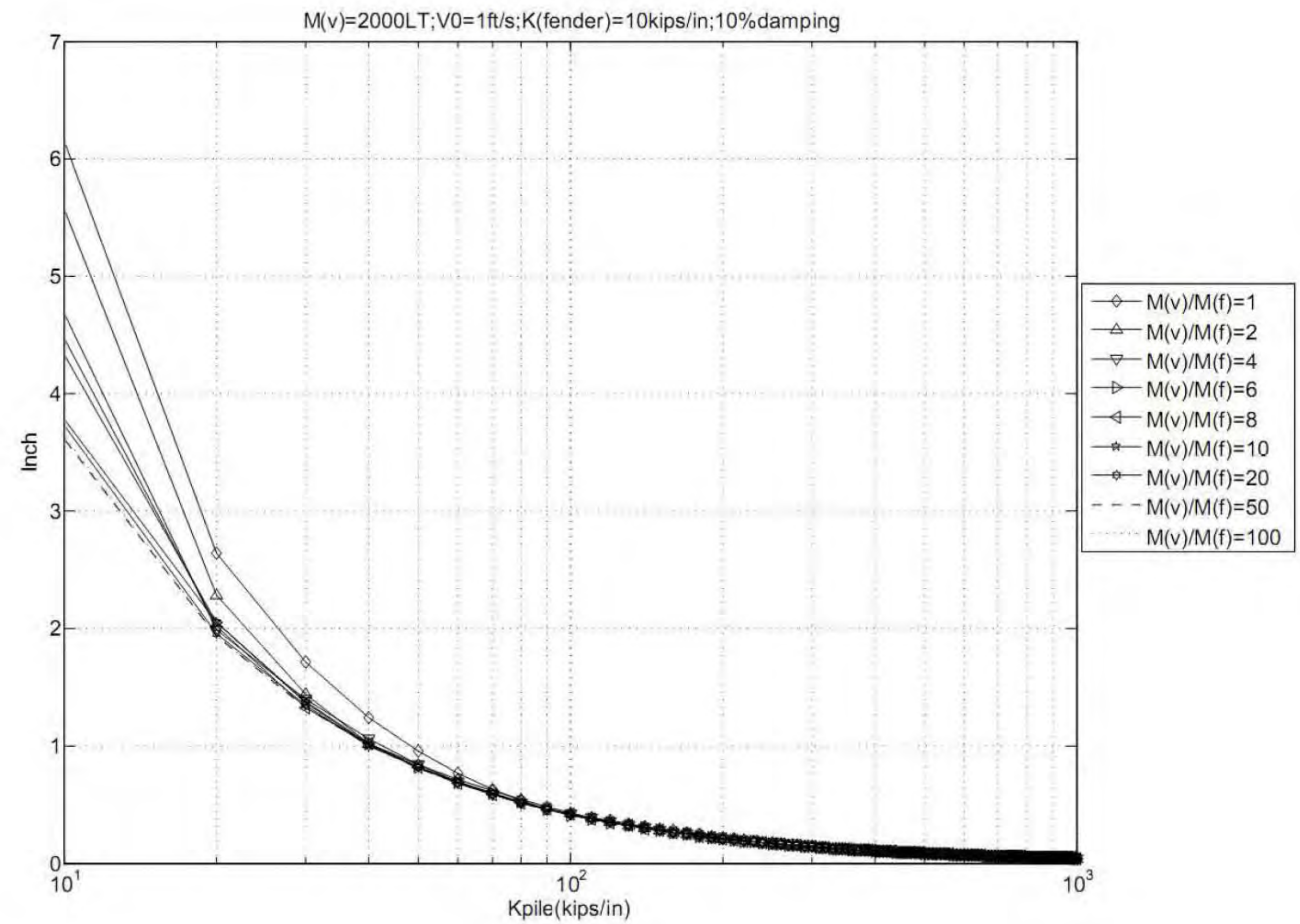


Fig. A.206 Displacement of the Piling System 2D-20b

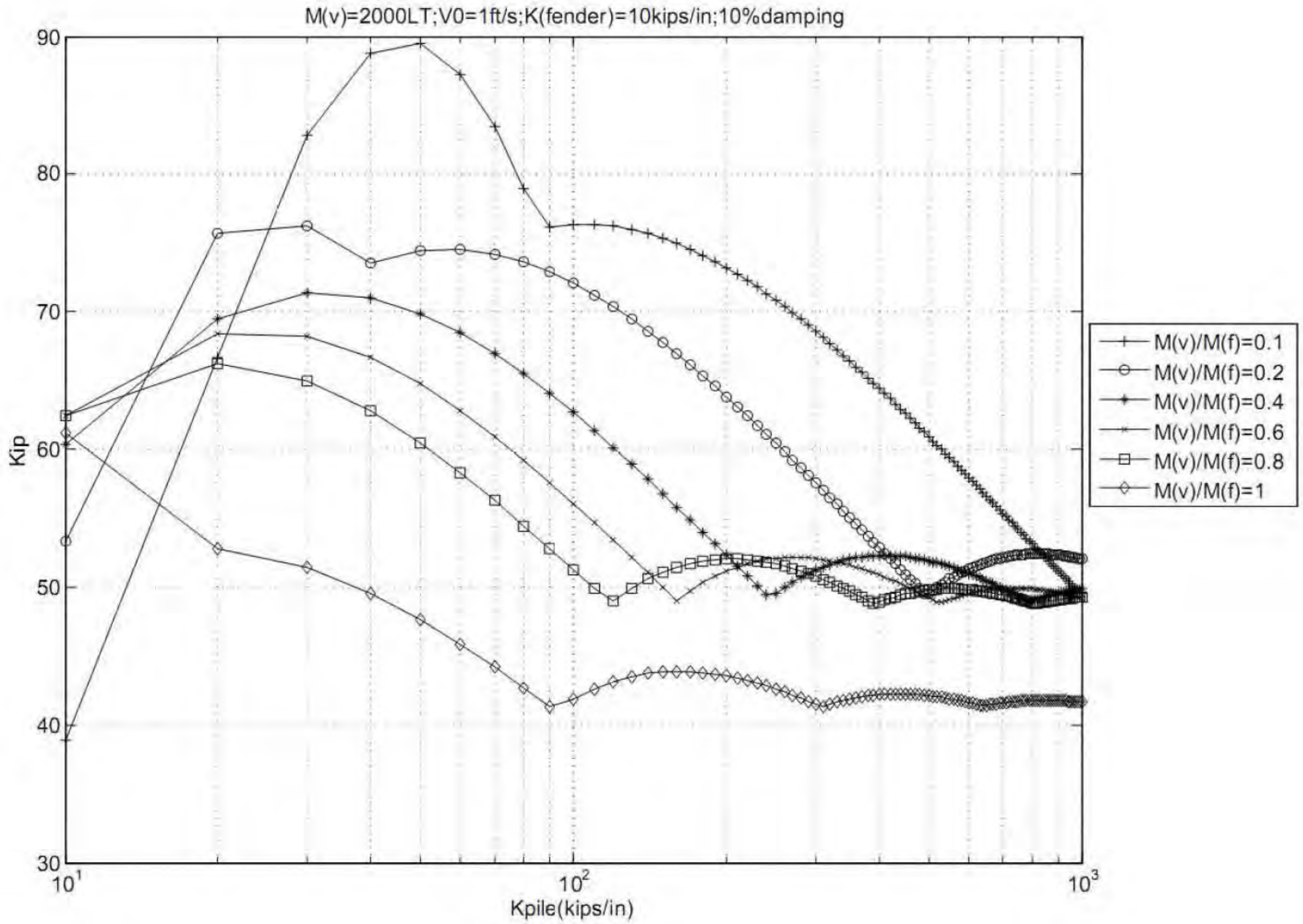


Fig. A.207 Reaction Force of the Piling System 2D-20a

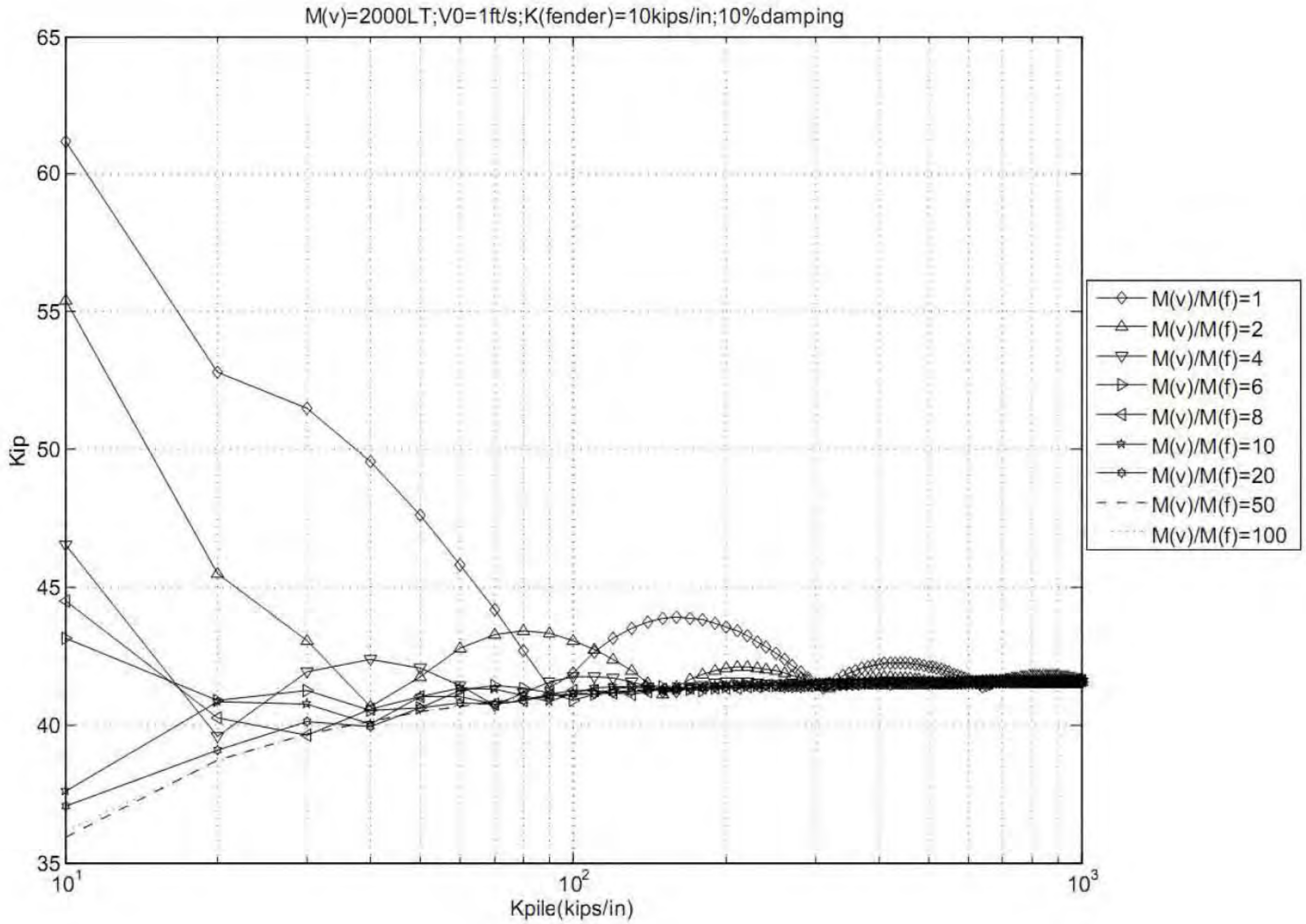


Fig. A.208 Reaction Force of the Piling System 2D-20b

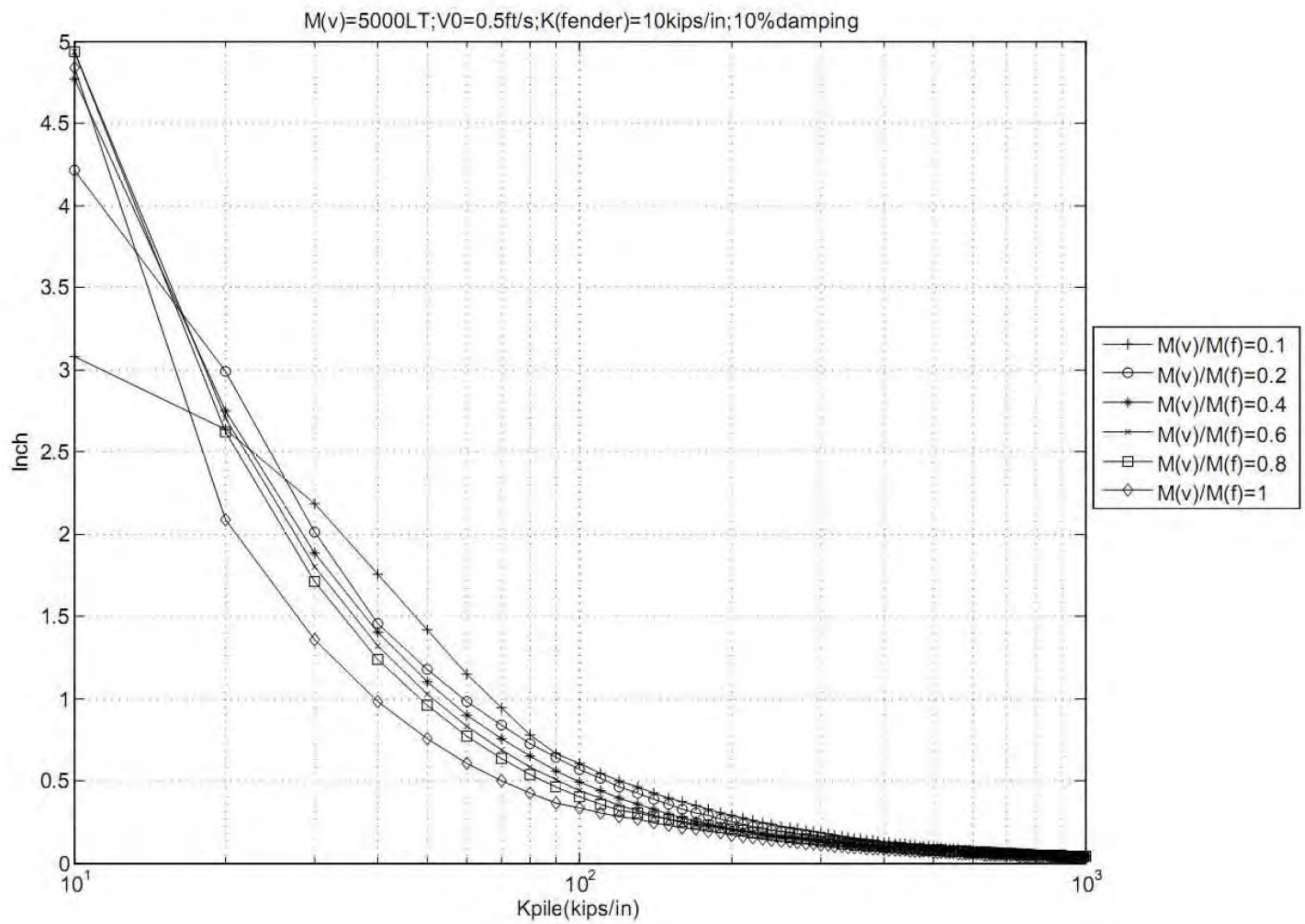


Fig. A.209 Displacement of the Piling System 2D-21a

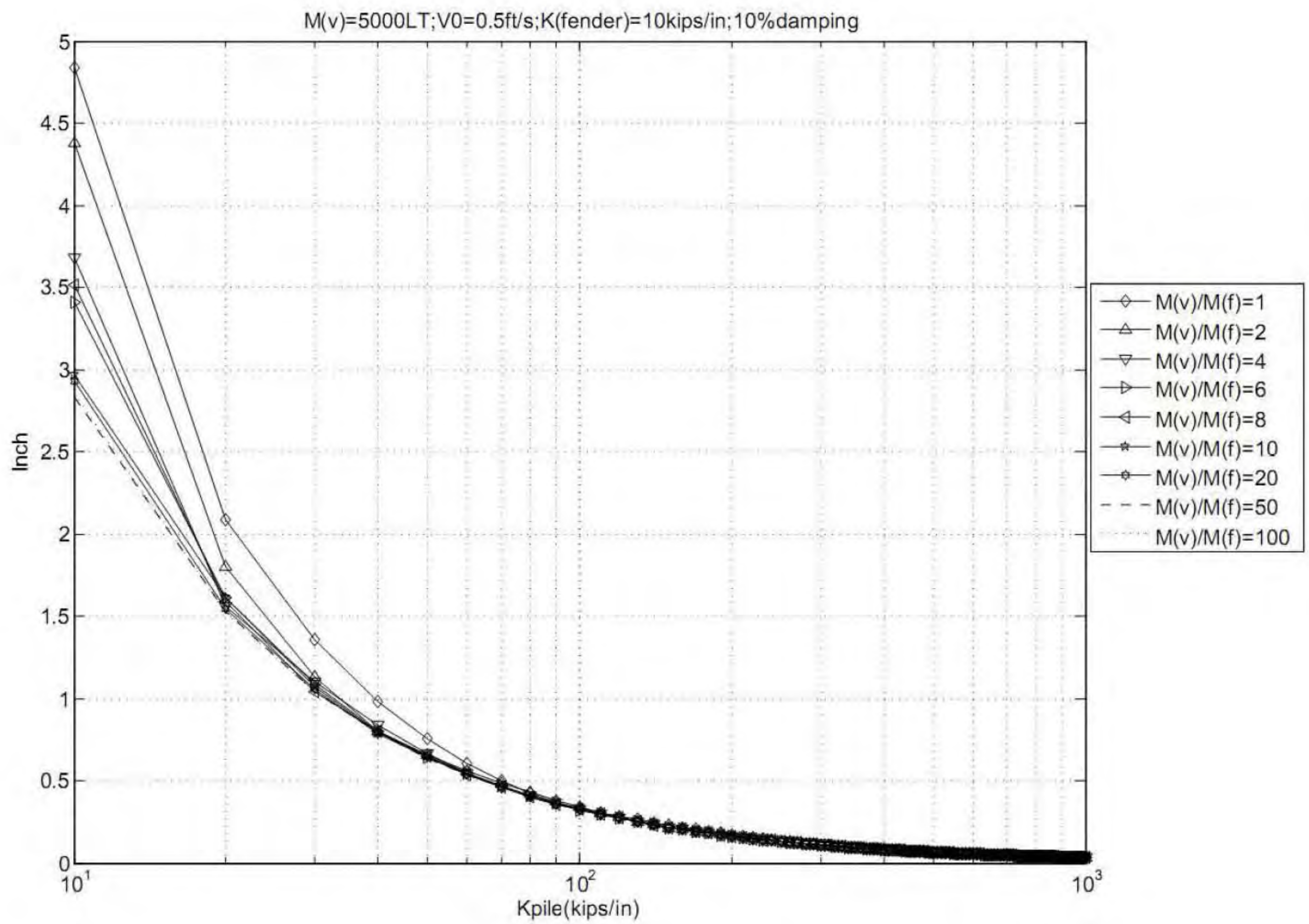


Fig. A.210 Displacement of the Piling System 2D-21b

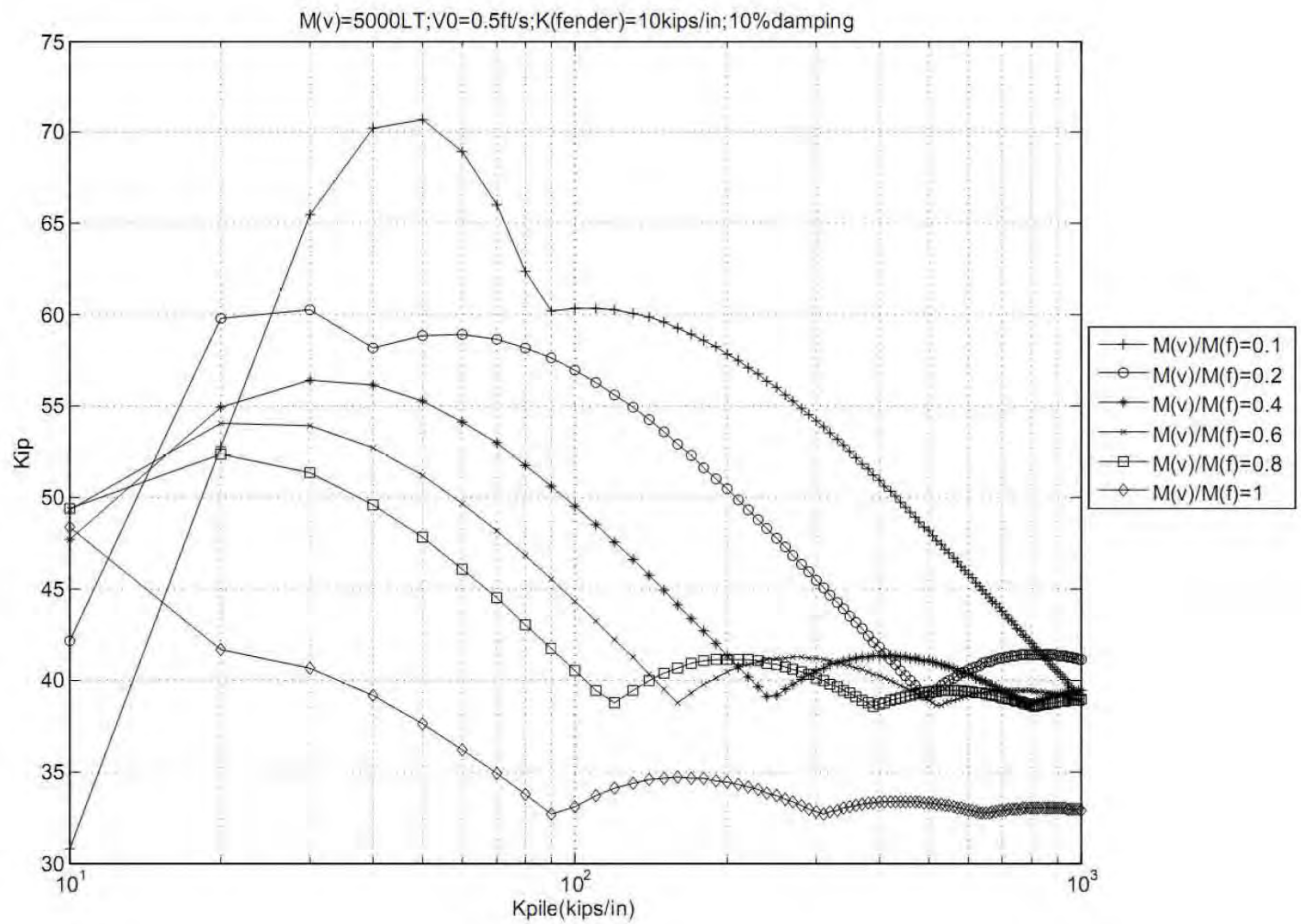


Fig. A.211 Reaction Force of the Piling System 2D-21a

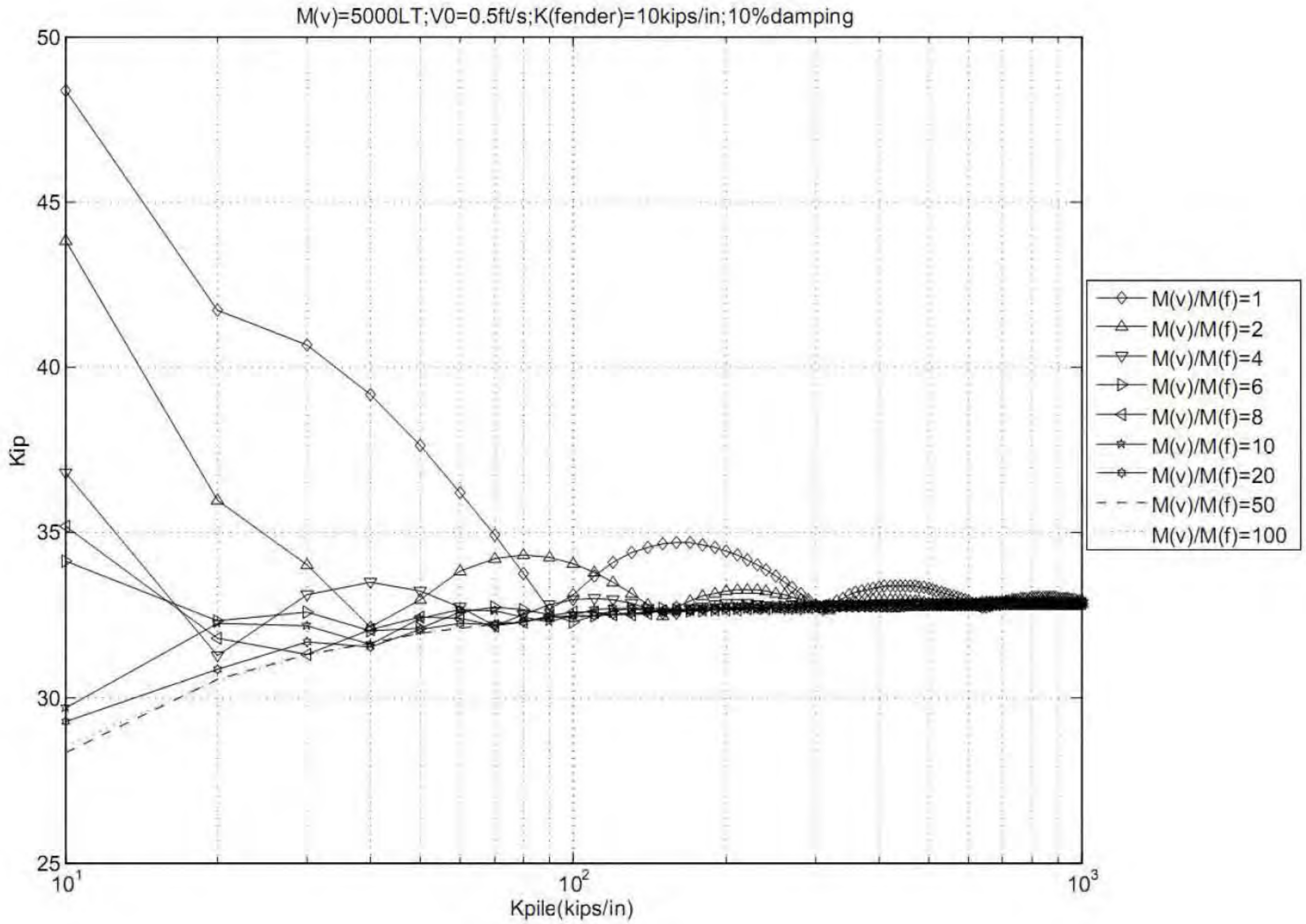


Fig. A.212 Reaction Force of the Piling System 2D-21b

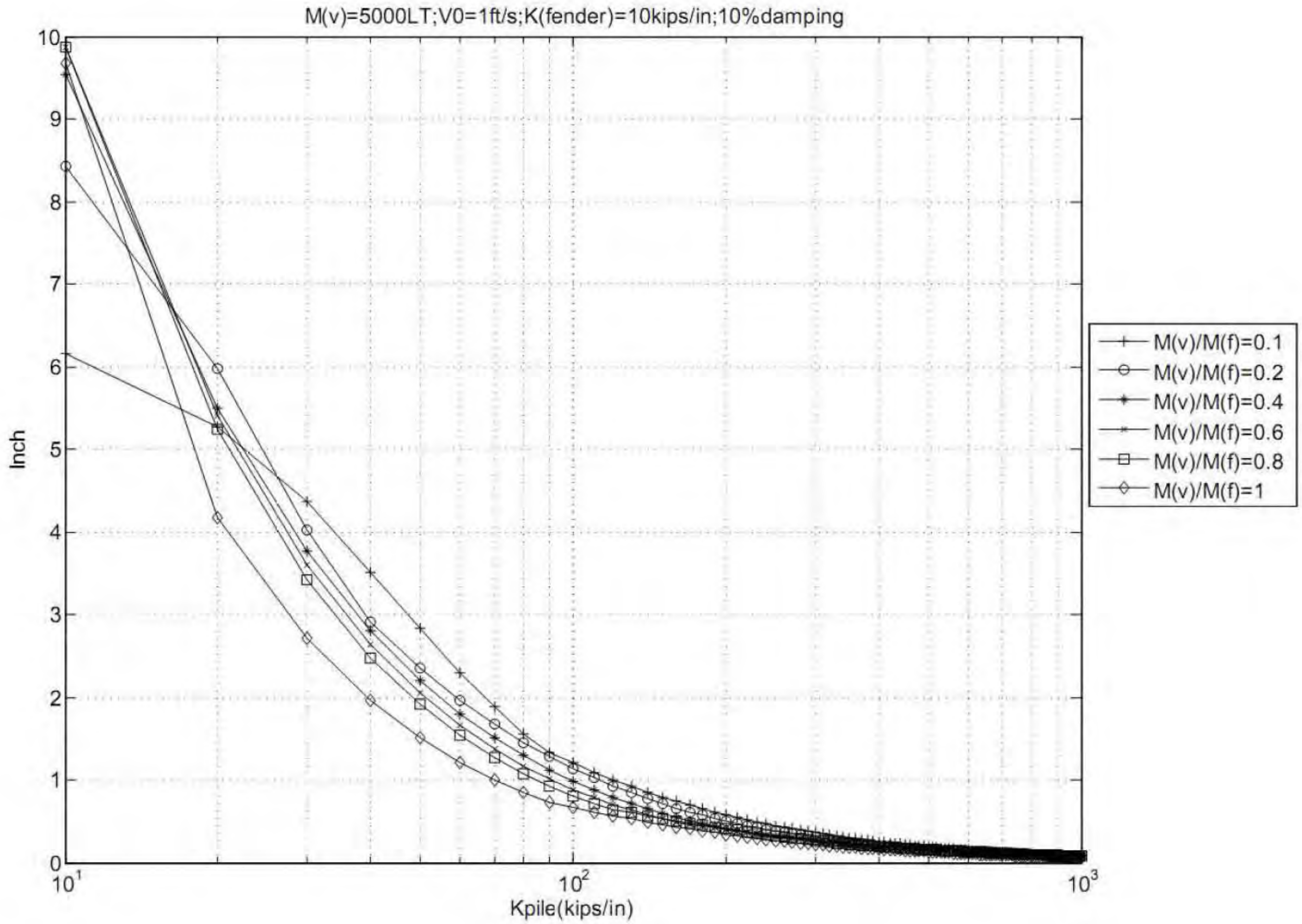


Fig. A.213 Displacement of the Piling System 2D-22a

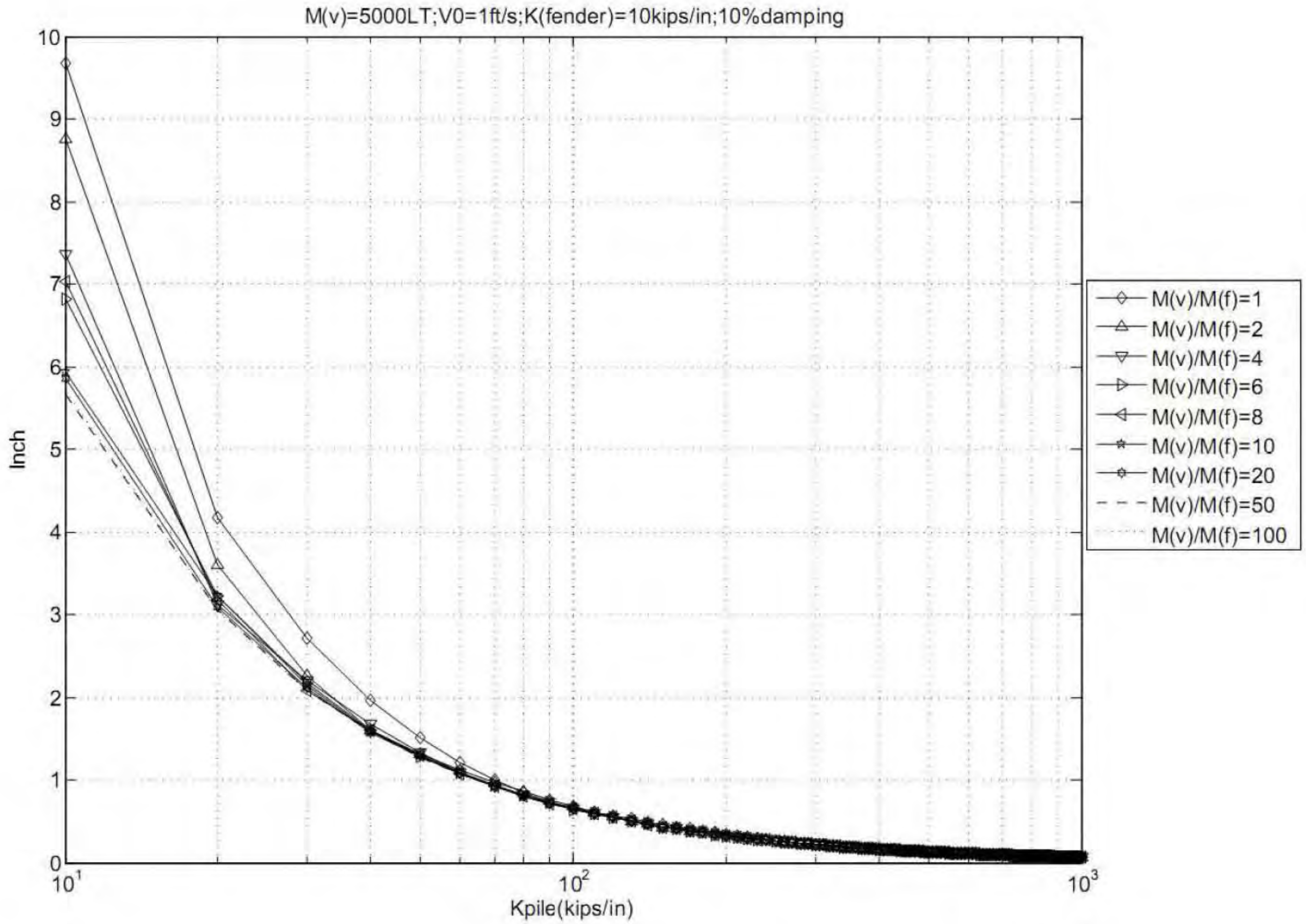


Fig. A.214 Displacement of the Piling System 2D-22b

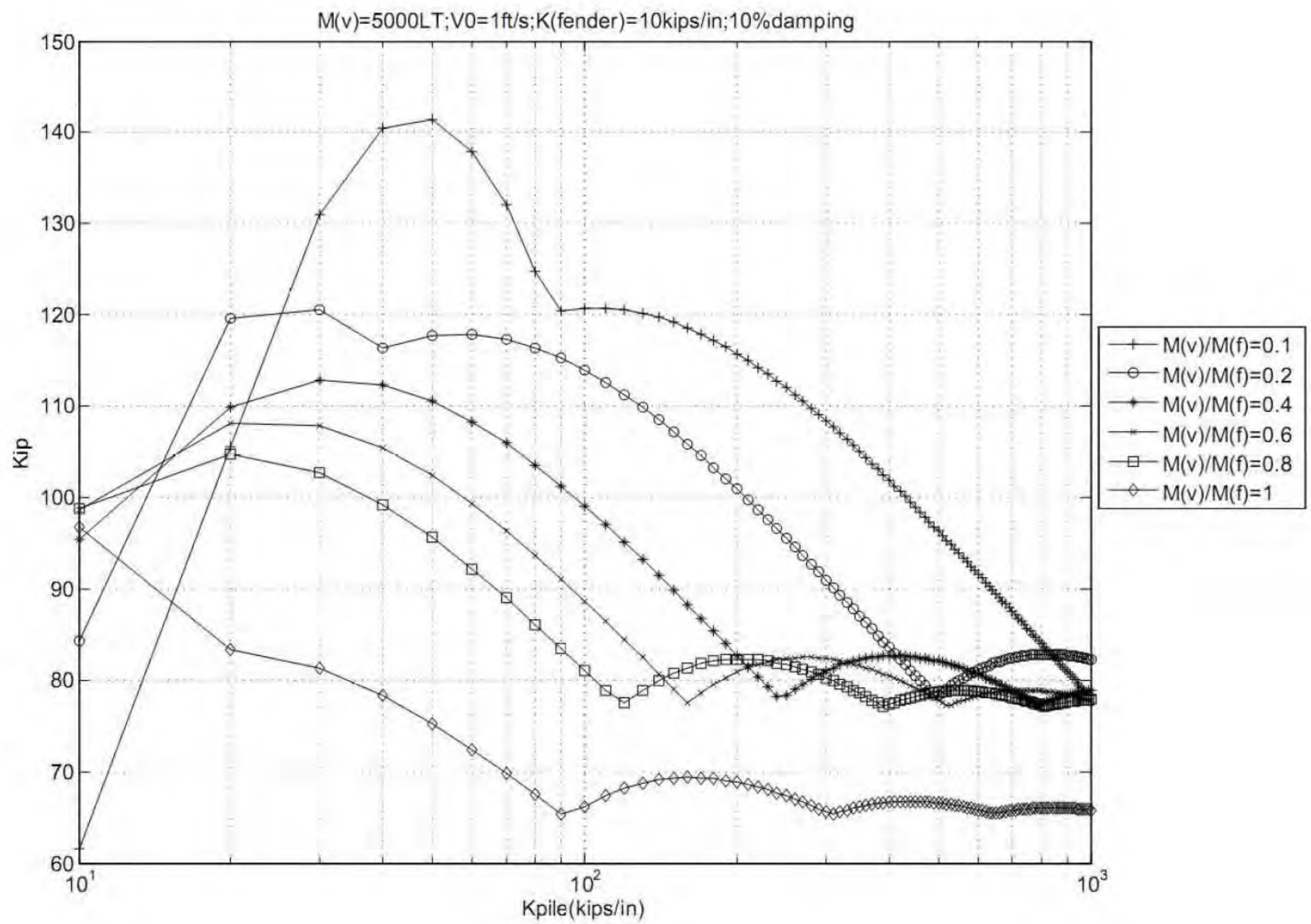


Fig. A.215 Reaction Force of the Piling System 2D-22a

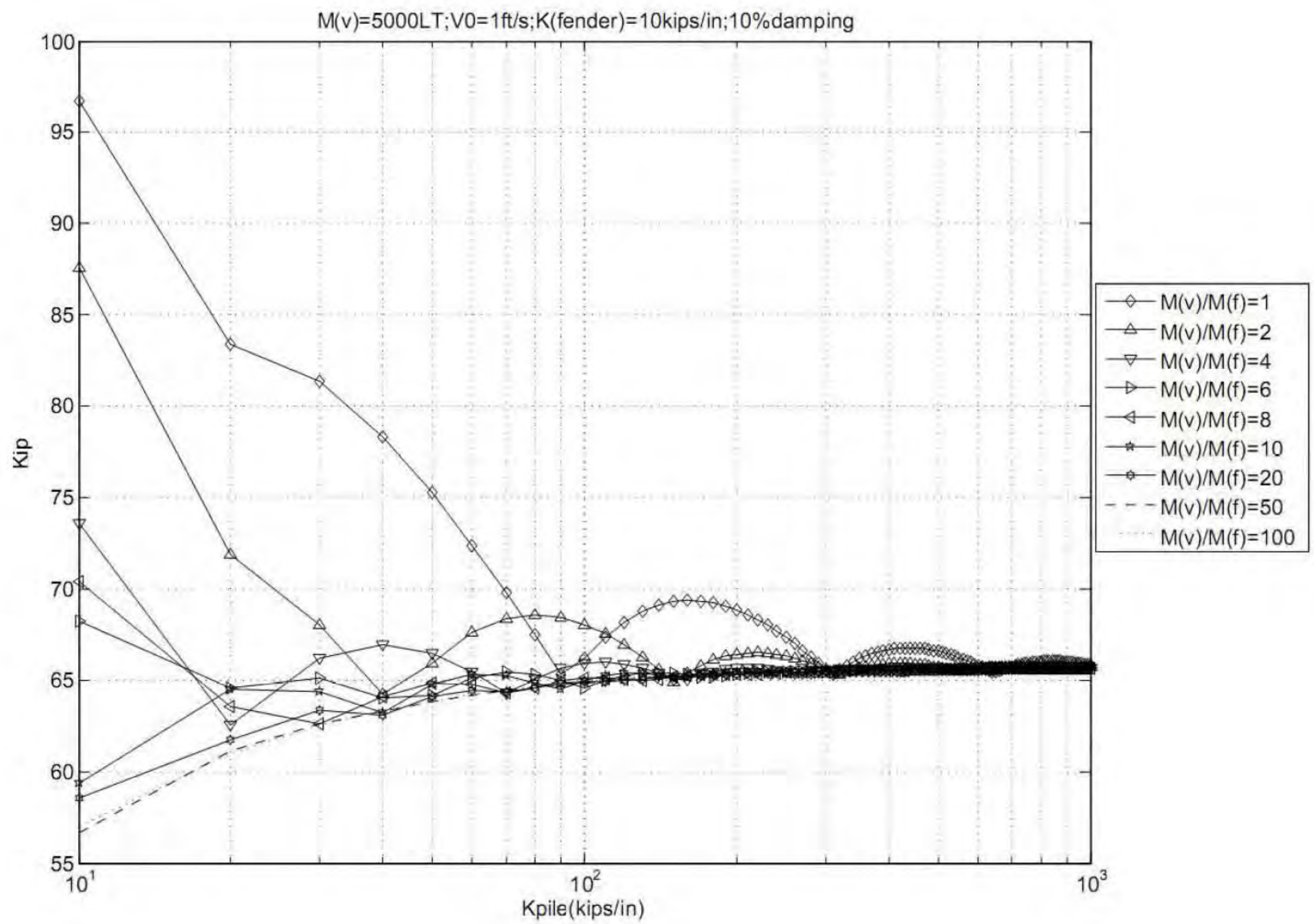


Fig. A.216 Reaction Force of the Piling System 2D-22b

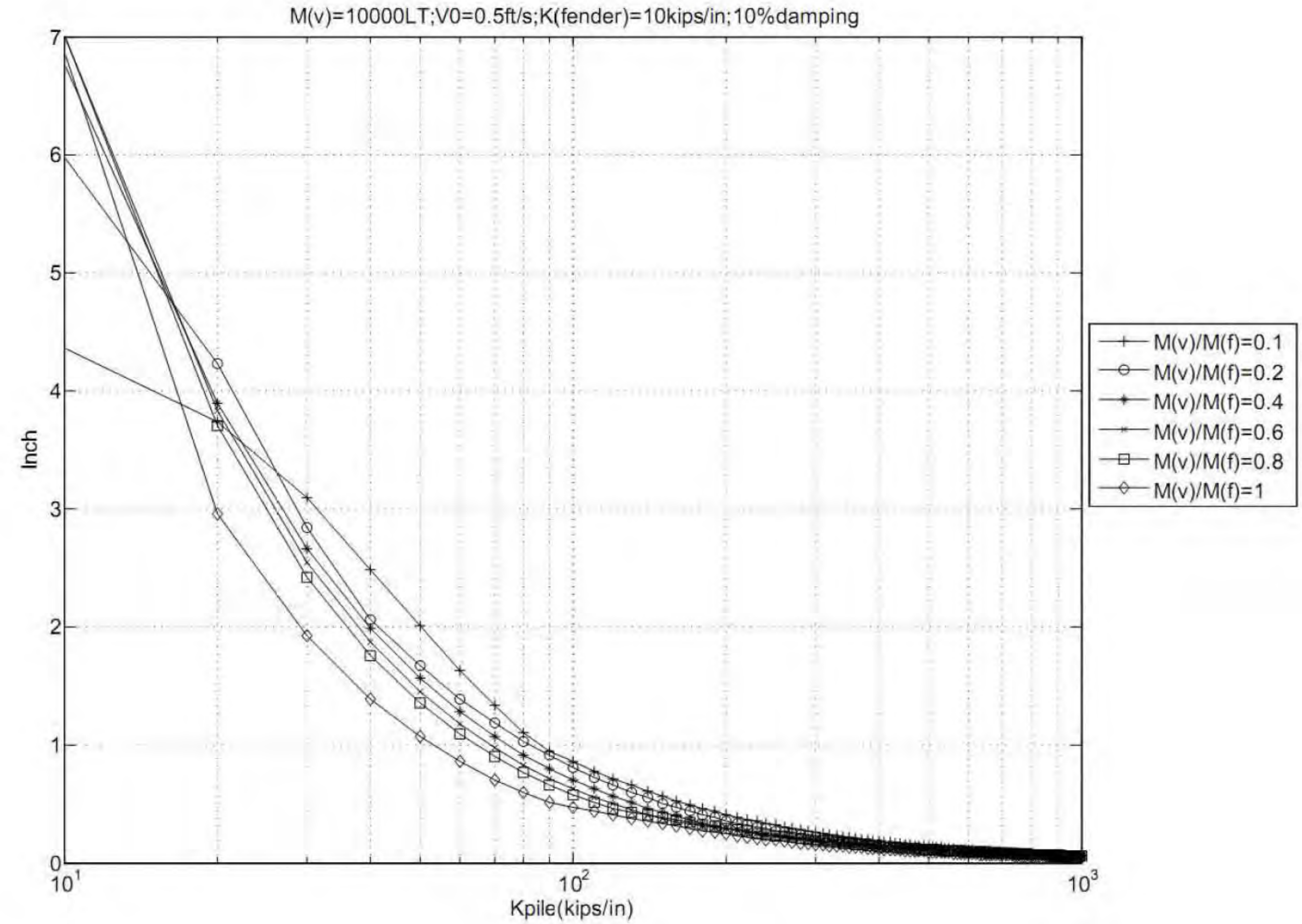


Fig. A.217 Displacement of the Piling System 2D-23a

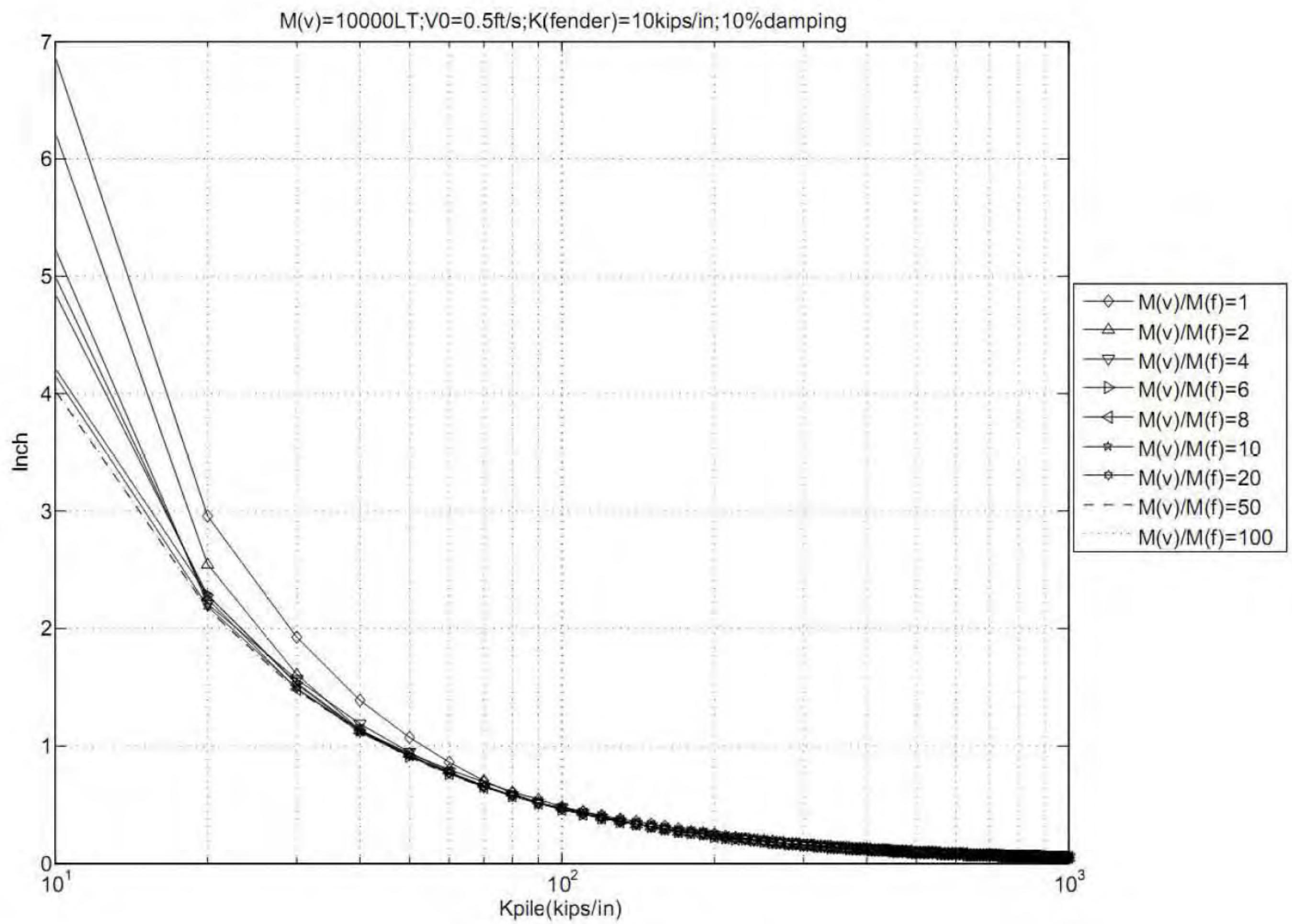


Fig. A.218 Displacement of the Piling System 2D-23b

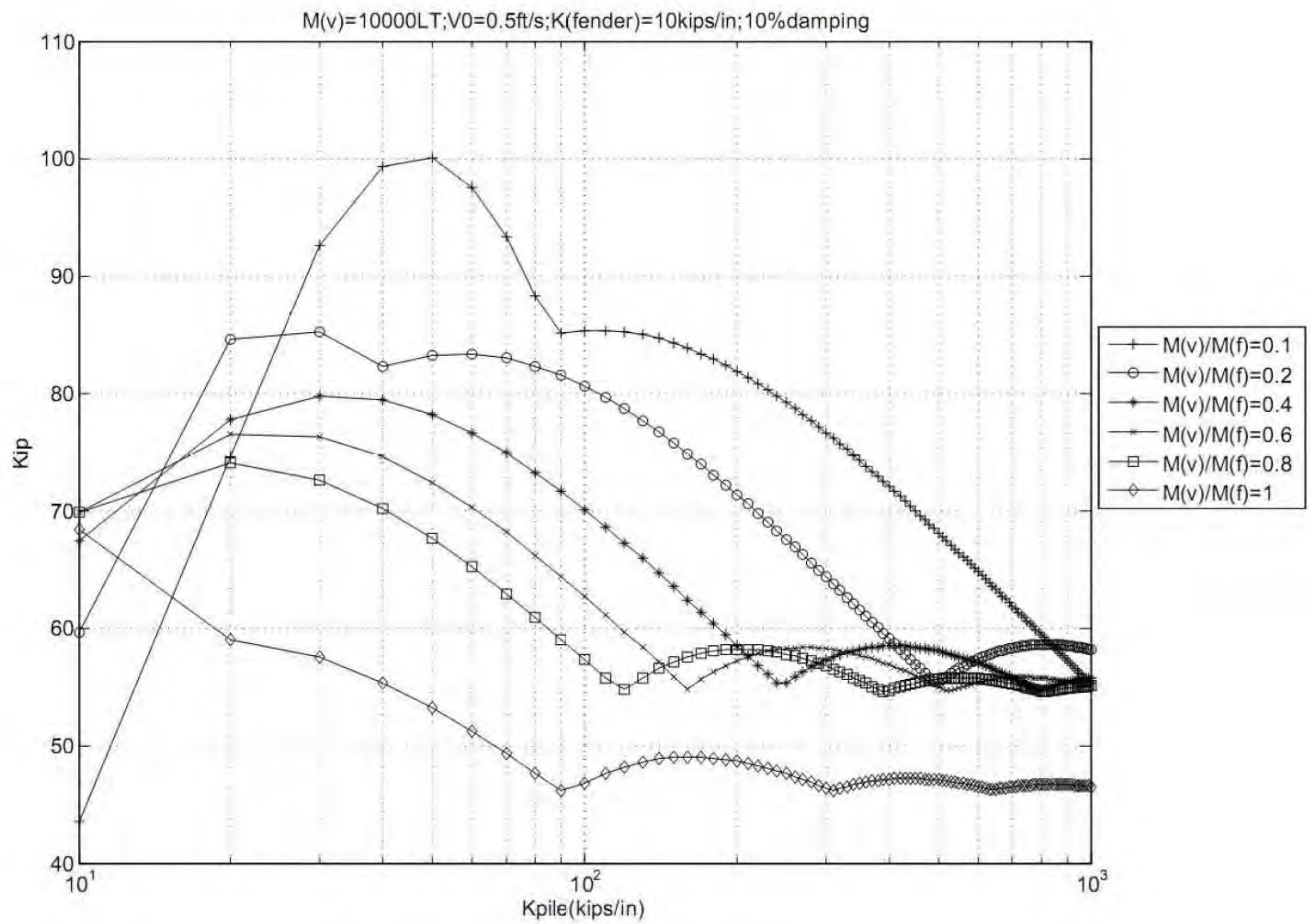


Fig. A.219 Reaction Force of the Piling System 2D-23a

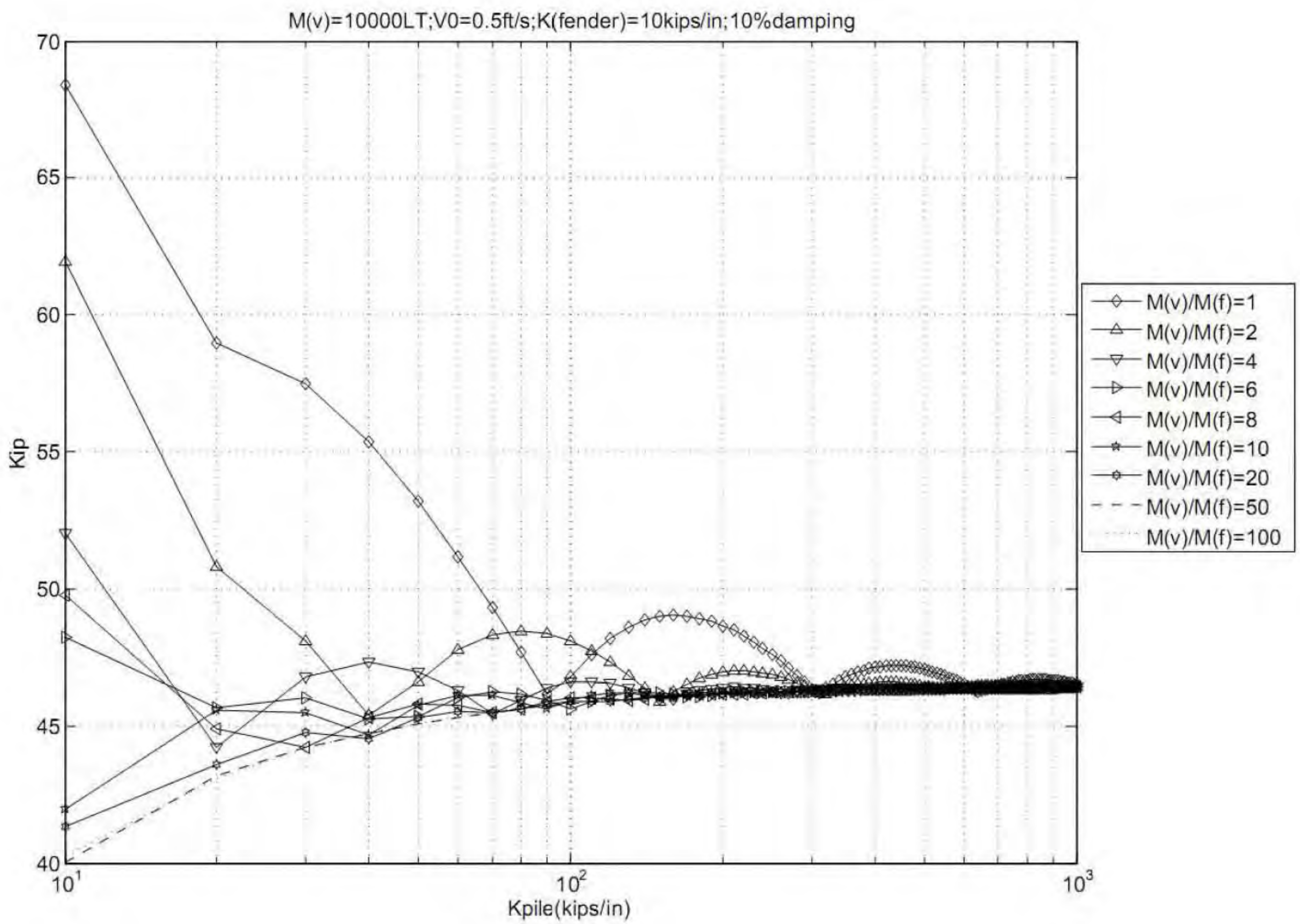


Fig. A.220 Reaction Force of the Piling System 2D-23b

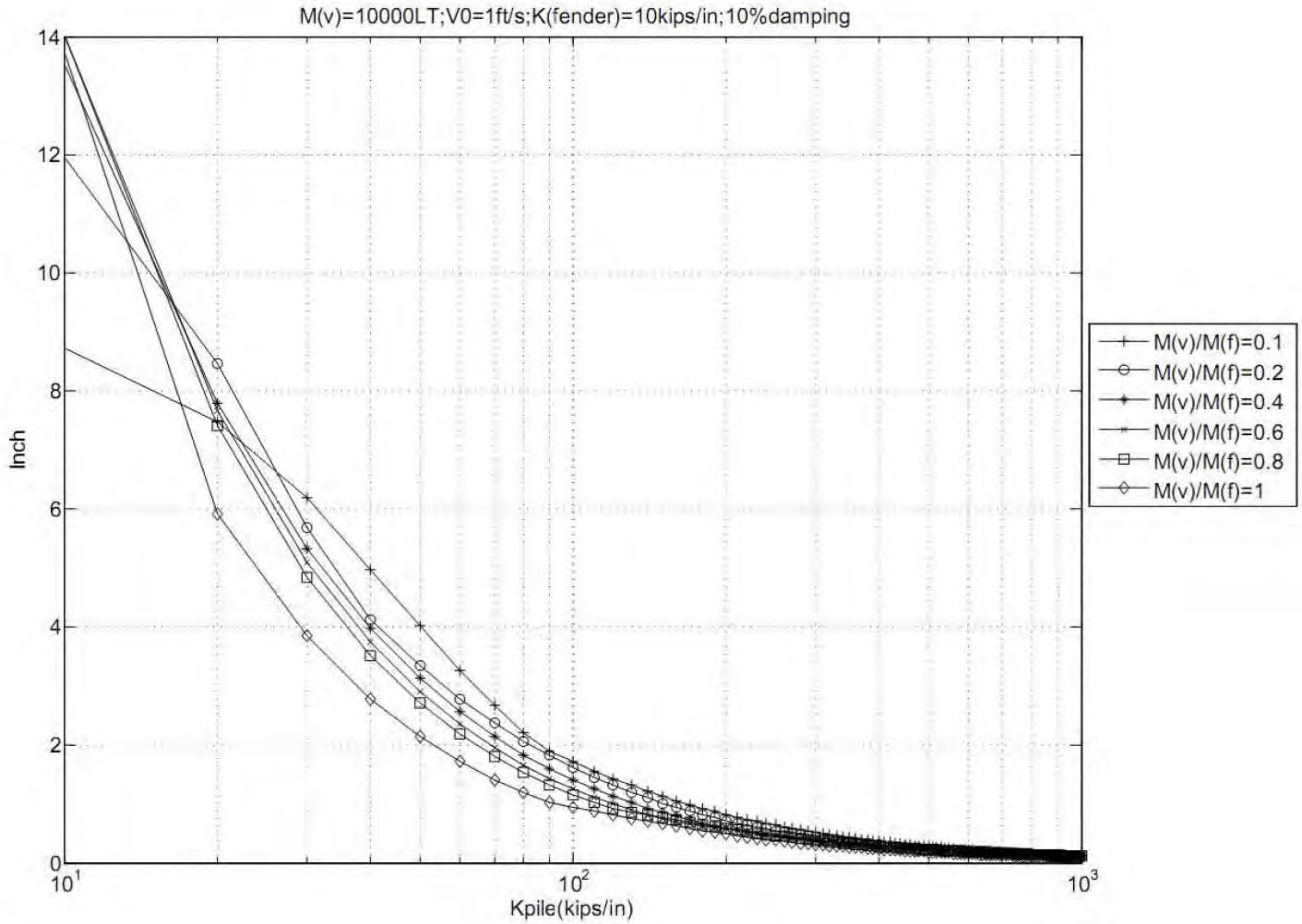


Fig. A.221 Displacement of the Piling System 2D-24a

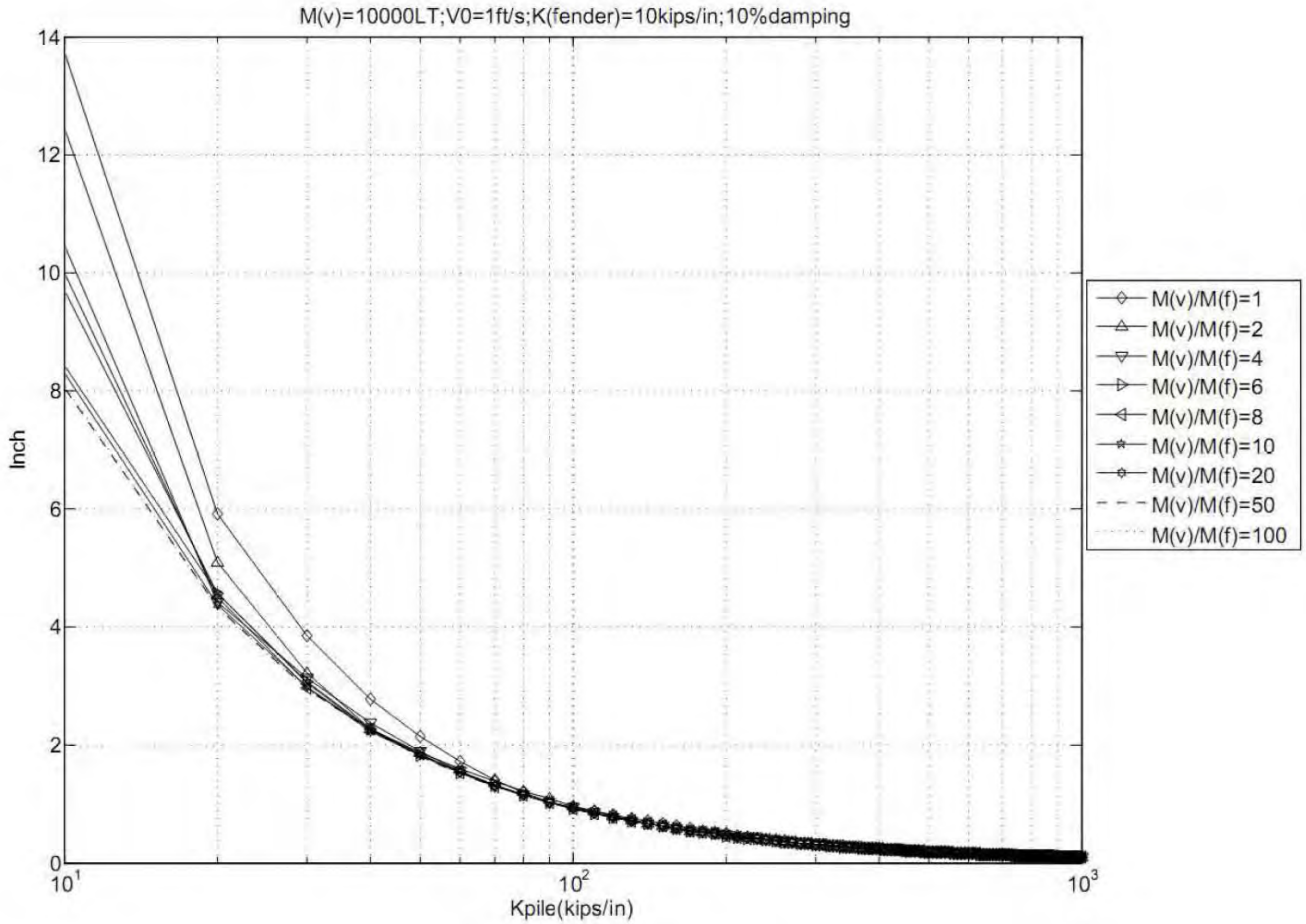


Fig. A.222 Displacement of the Piling System 2D-24b

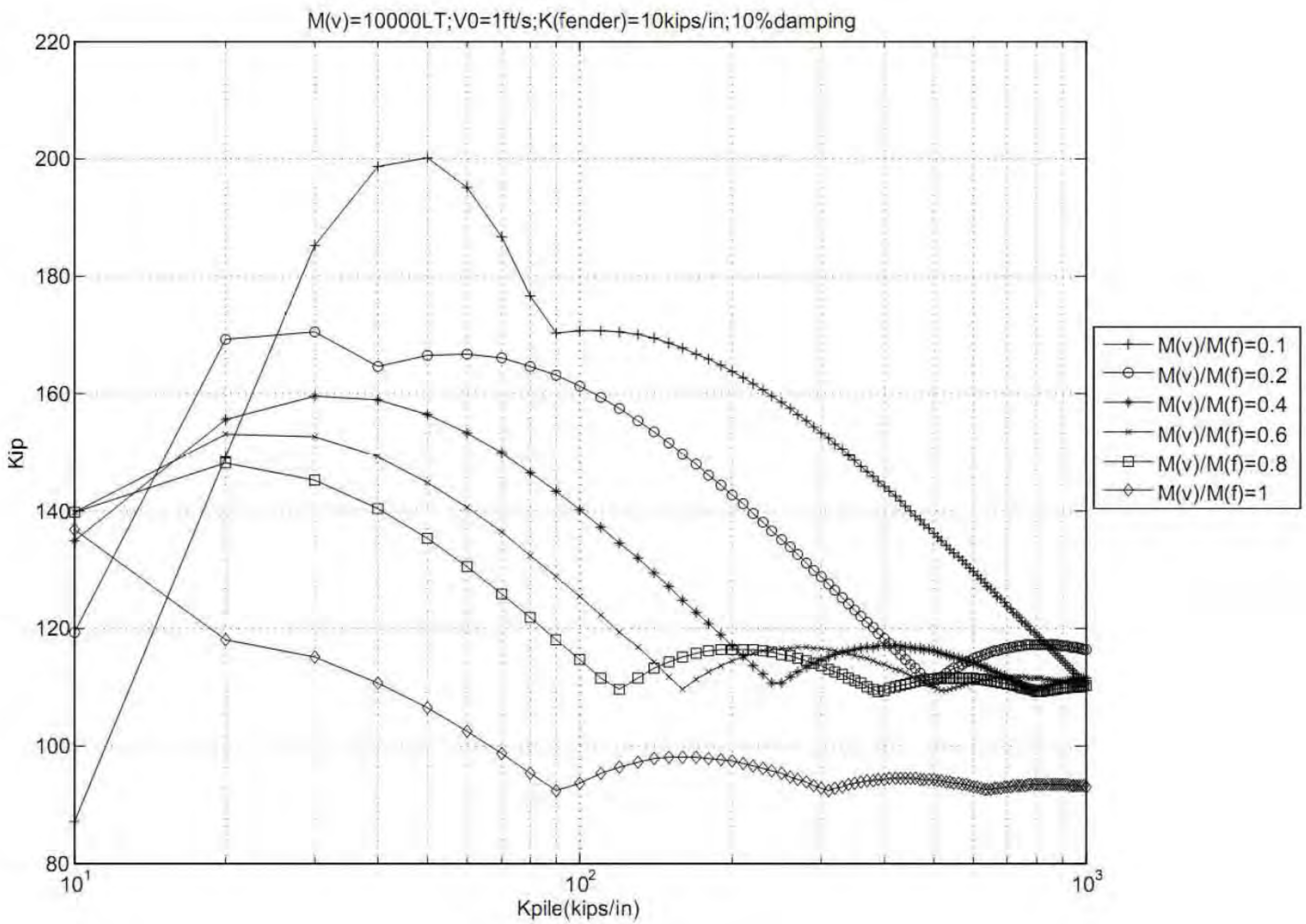


Fig. A.223 Reaction Force of the Piling System 2D-24a

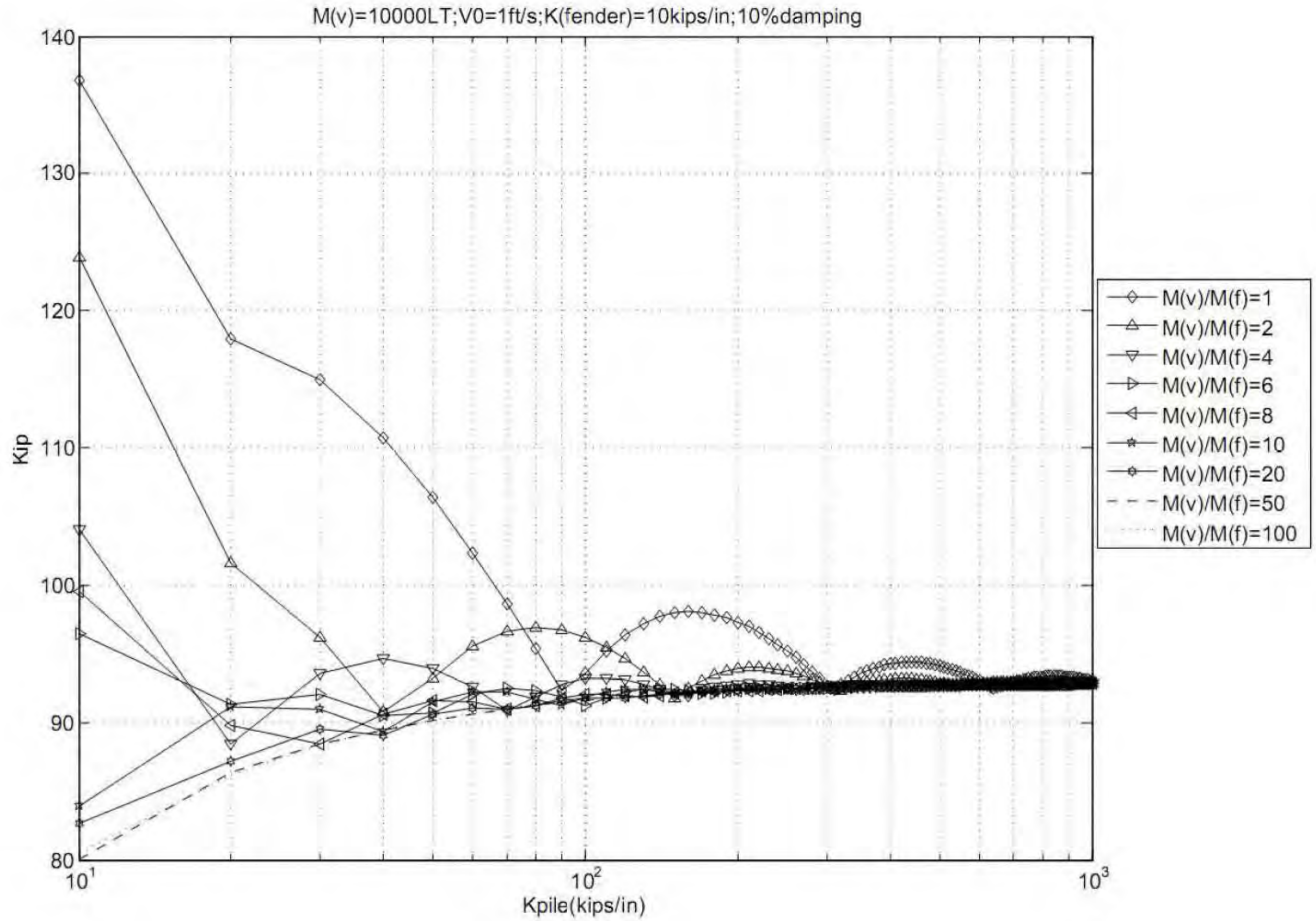


Fig. A.224 Reaction Force of the Piling System 2D-24b

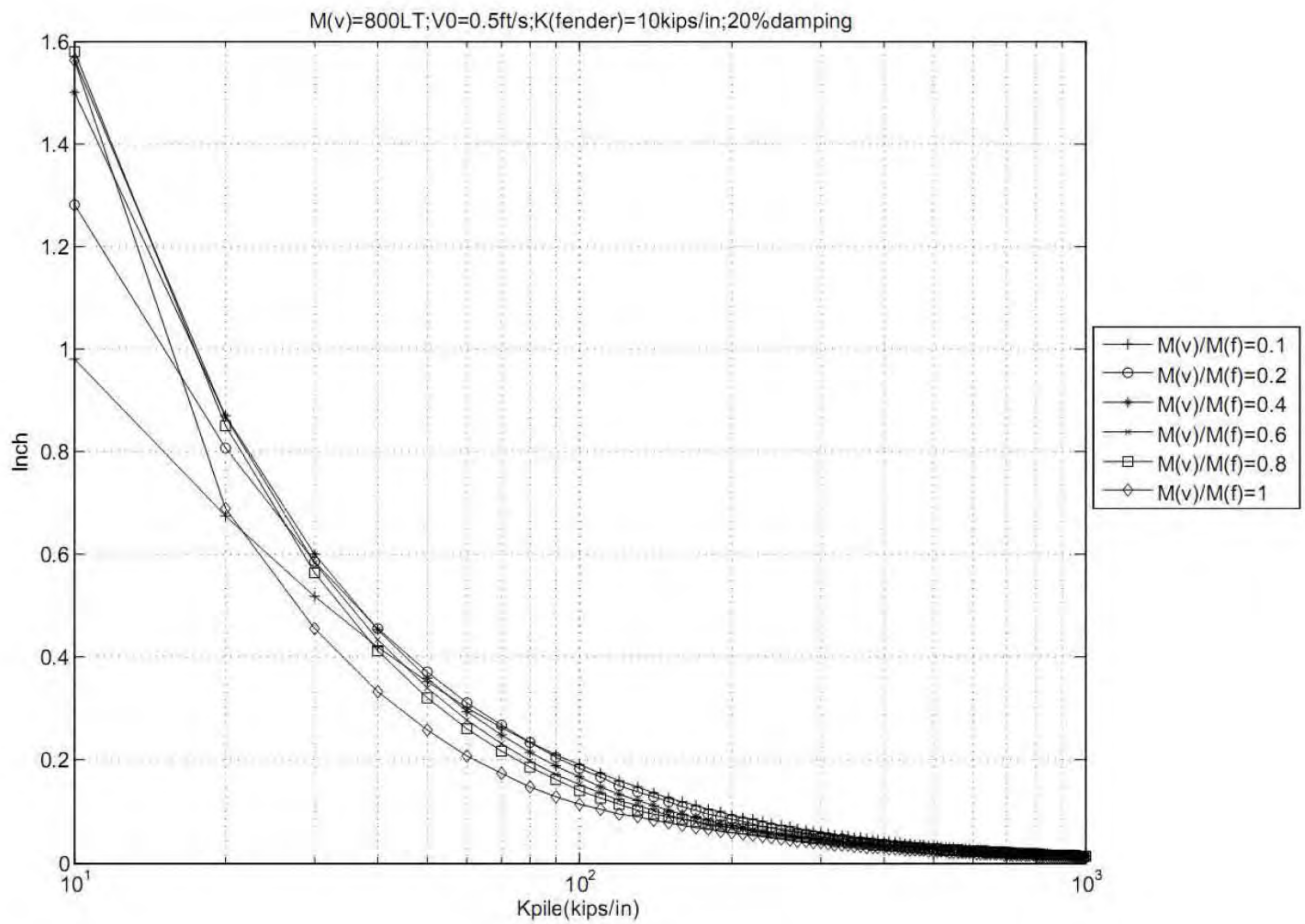


Fig. A.225 Displacement of the Piling System 2D-25a

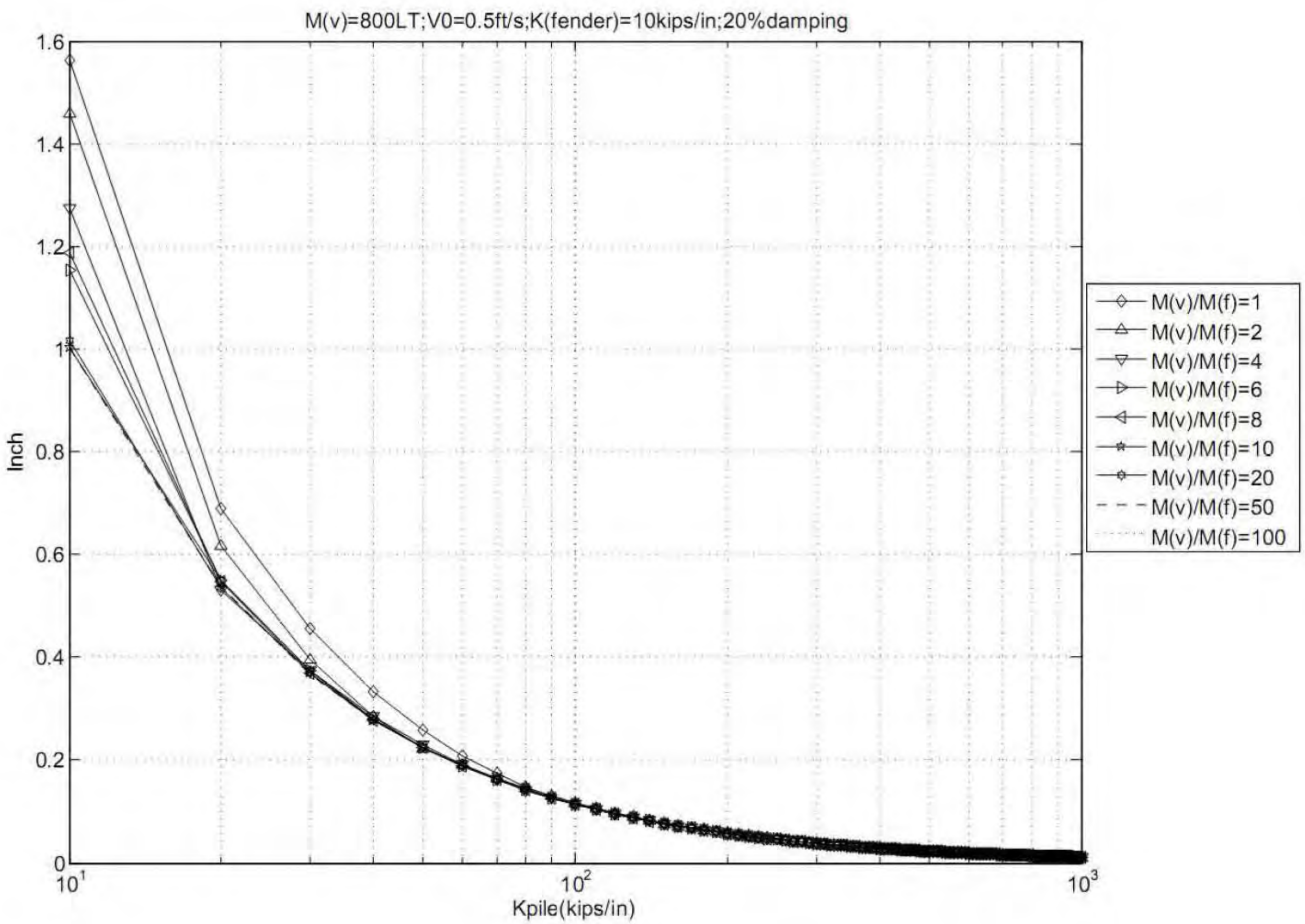


Fig. A.226 Displacement of the Piling System 2D-25b

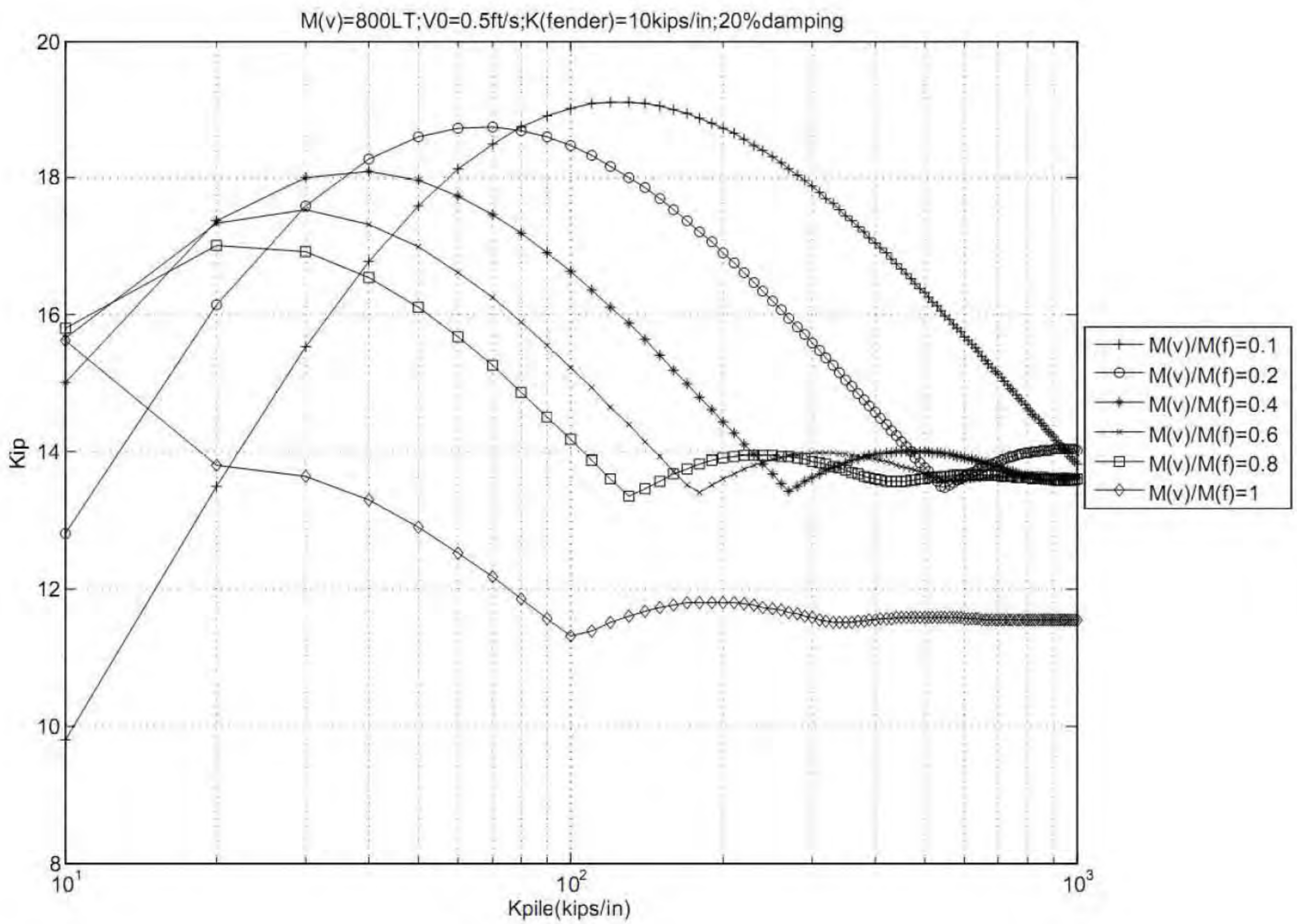


Fig. A.227 Reaction Force of the Piling System 2D-25a

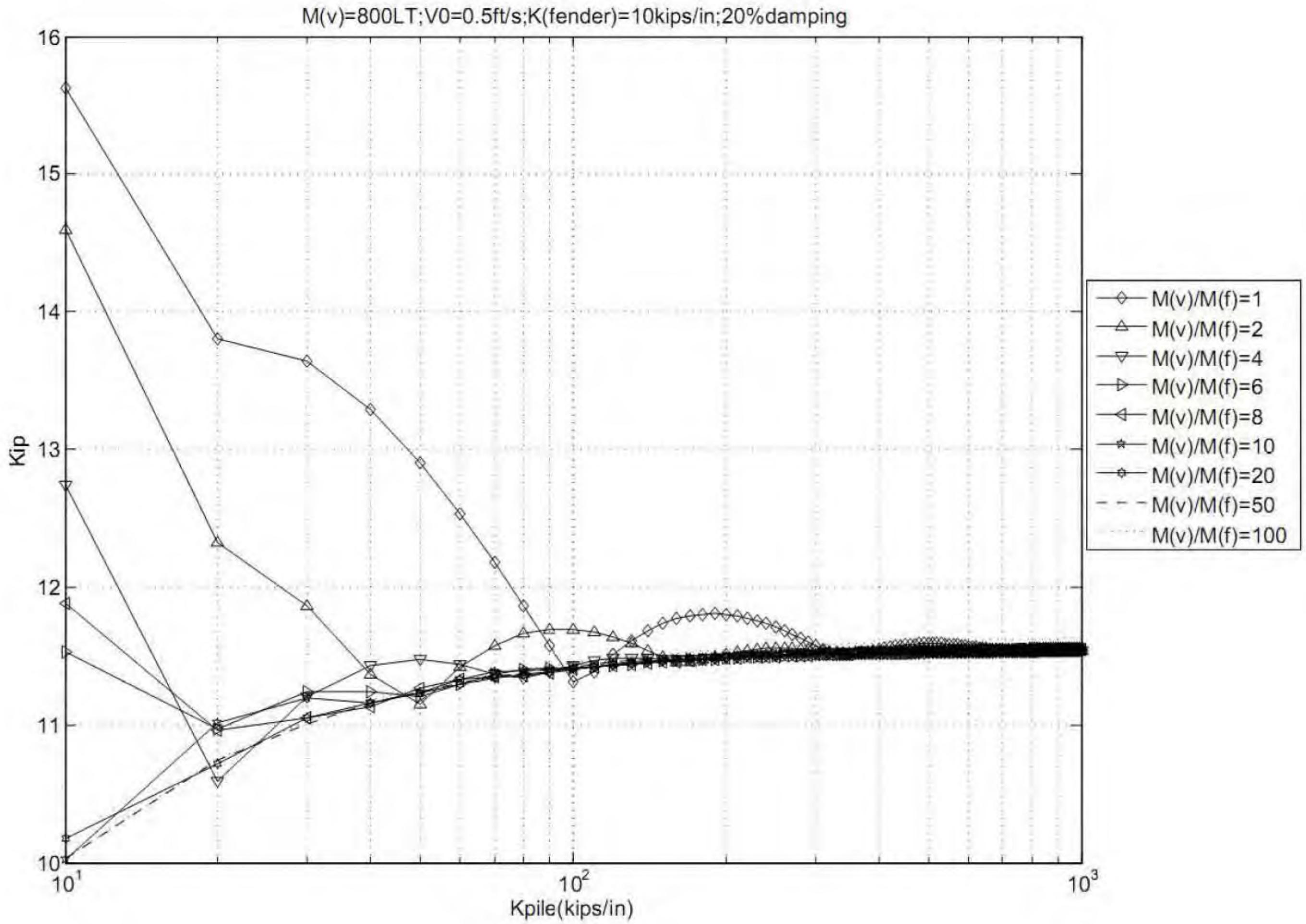


Fig. A.228 Reaction Force of the Piling System 2D-25b

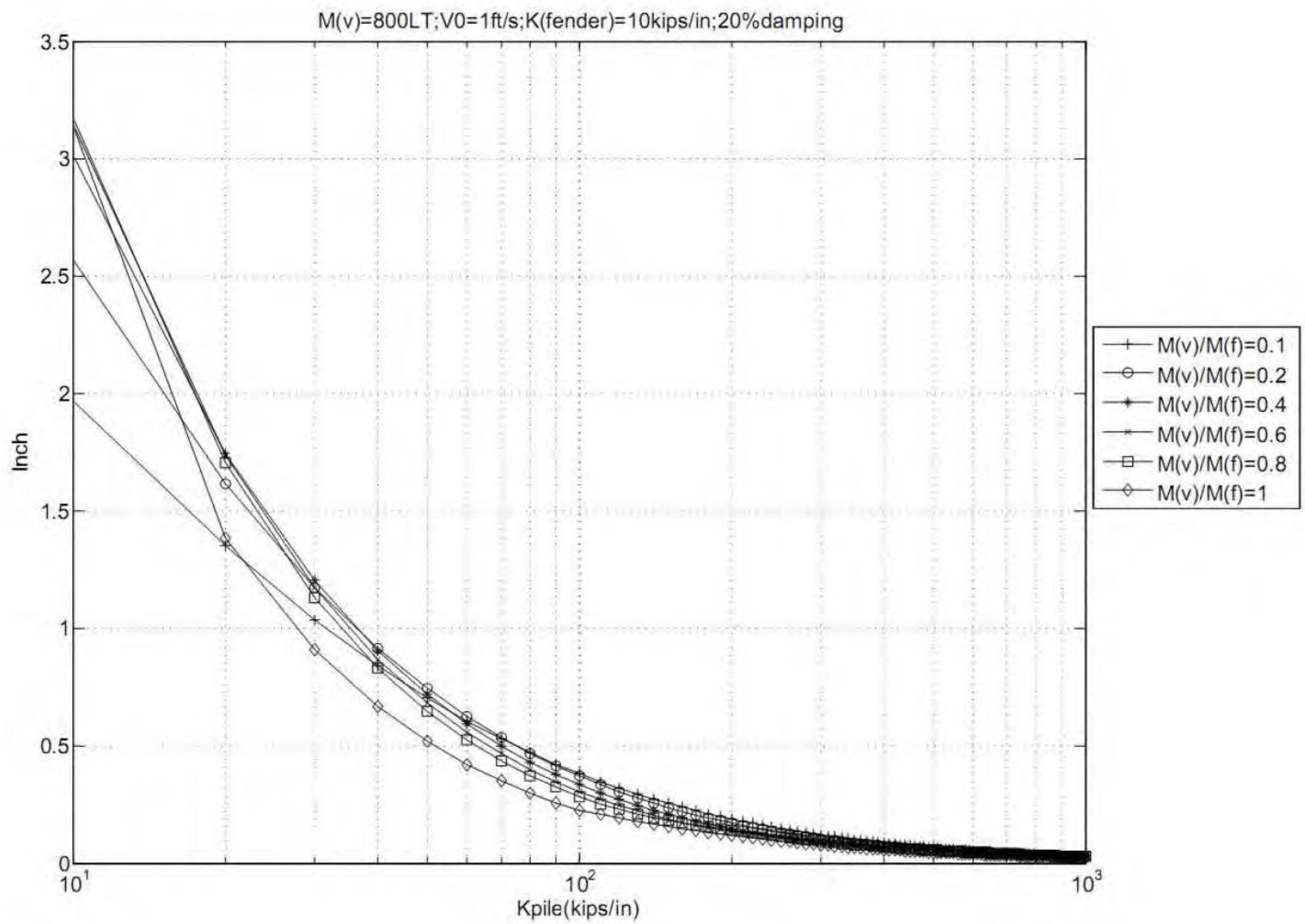


Fig. A.229 Displacement of the Piling System 2D-26a

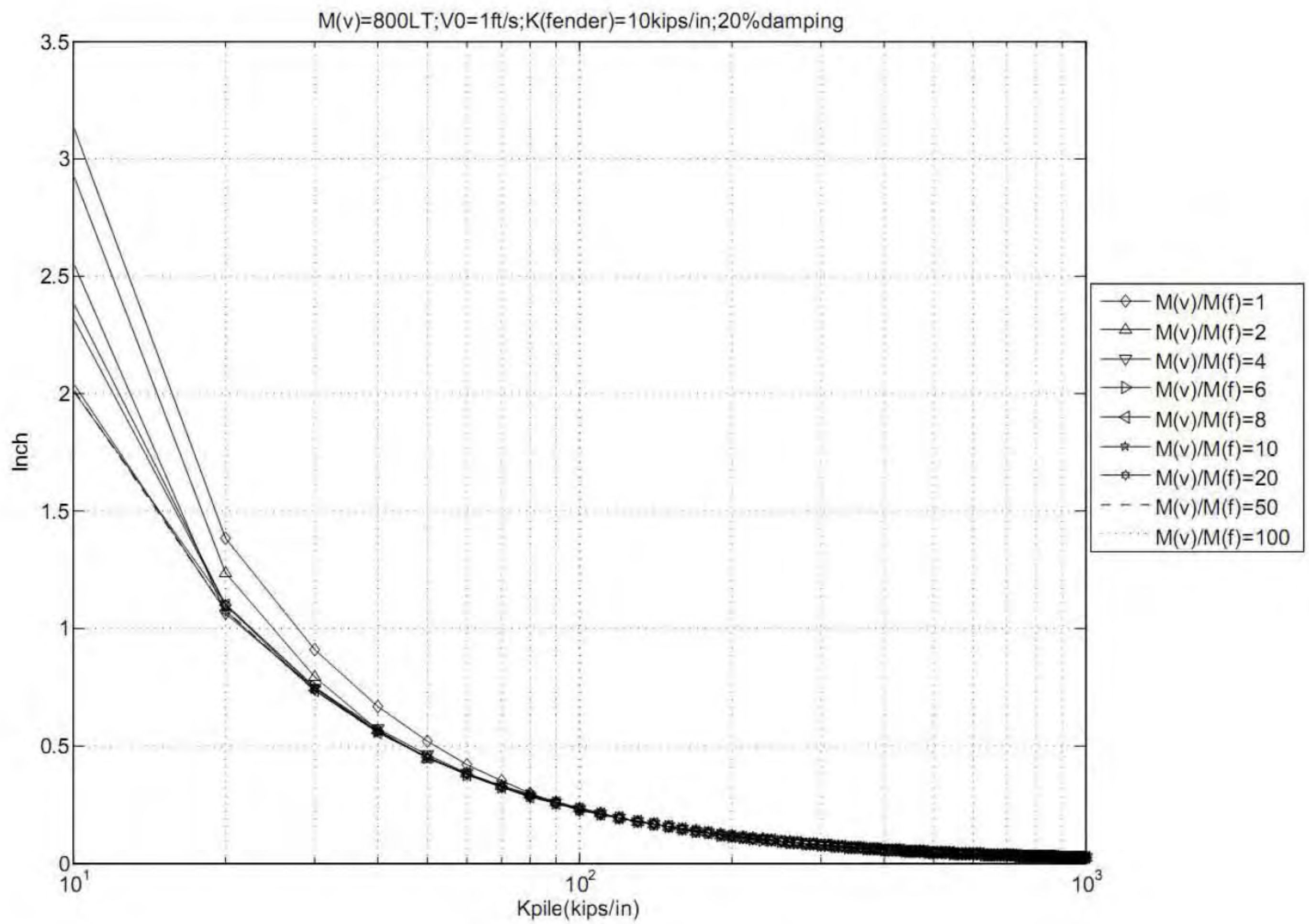


Fig. A.230 Displacement of the Piling System 2D-26b

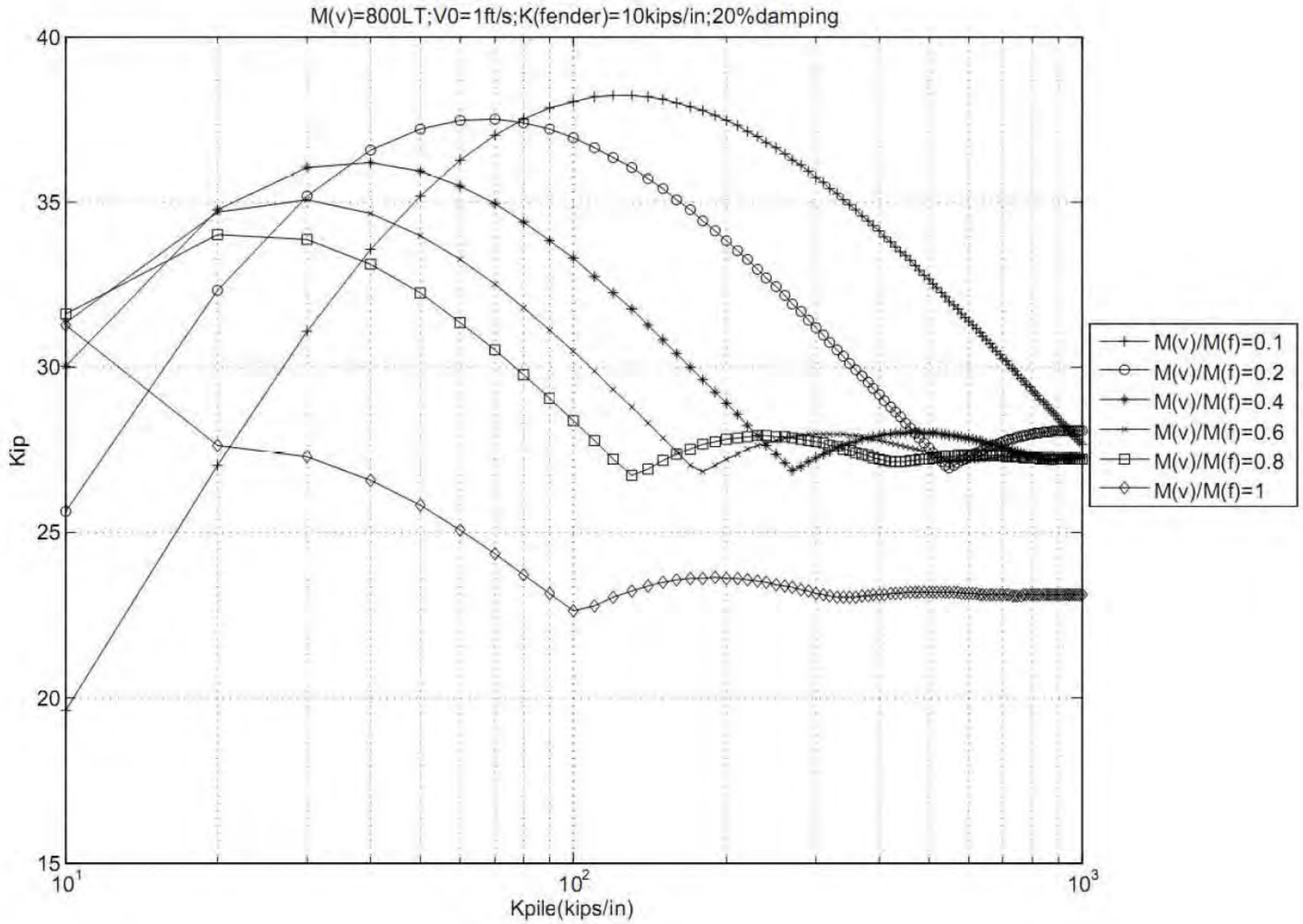


Fig. A.231 Reaction Force of the Piling System 2D-26a

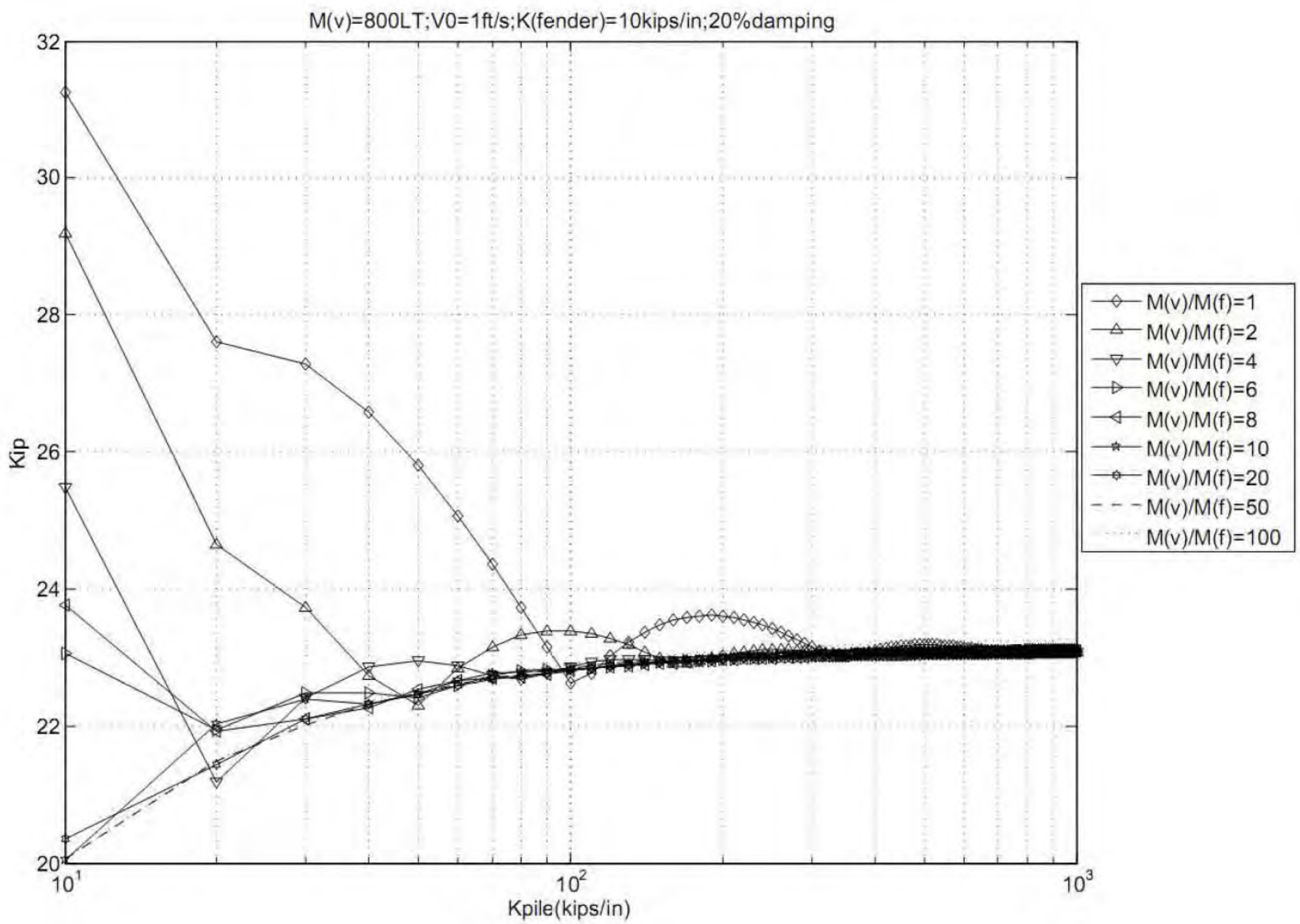


Fig. A.232 Reaction Force of the Piling System 2D-26b

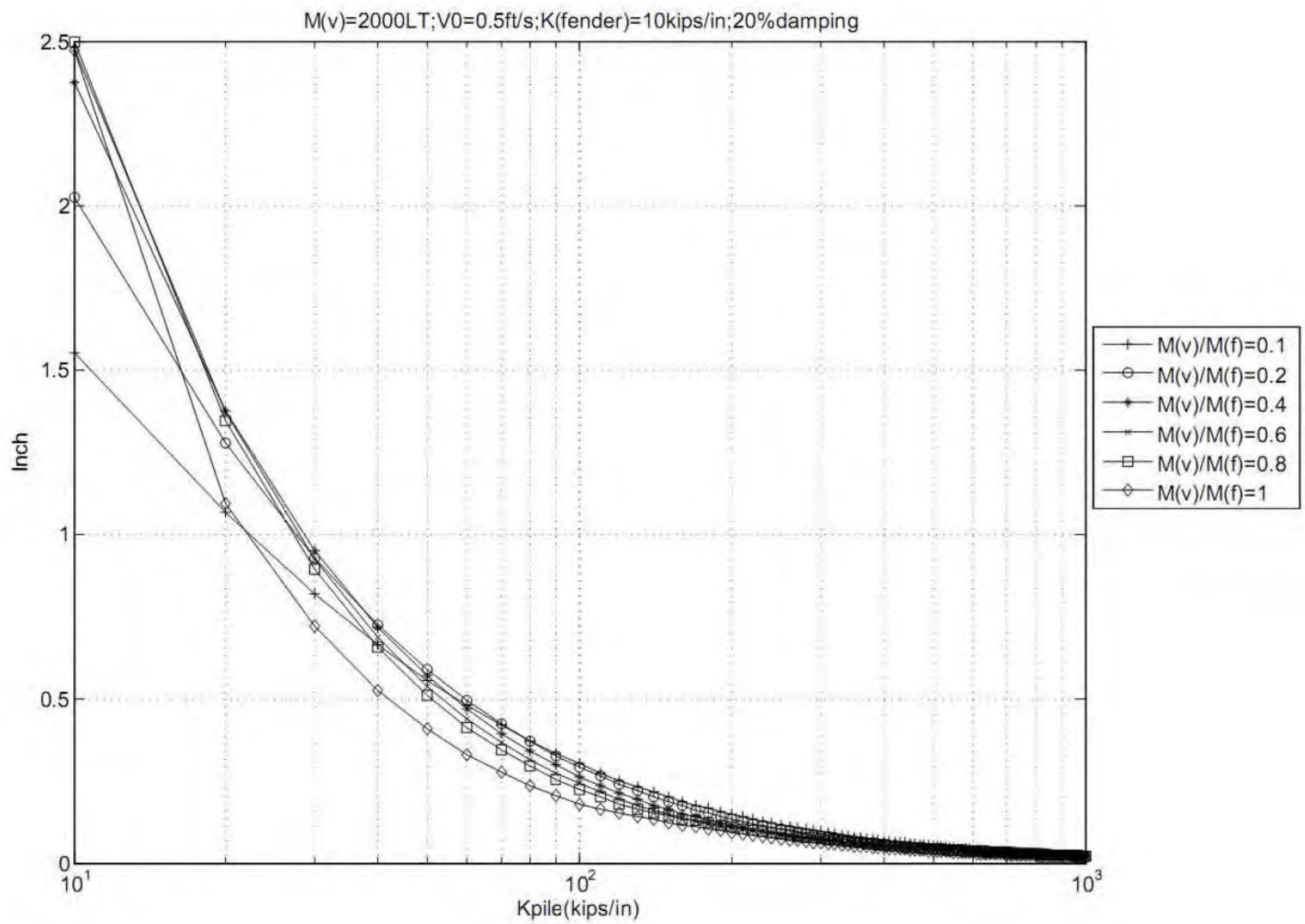


Fig. A.233 Displacement of the Piling System 2D-27a

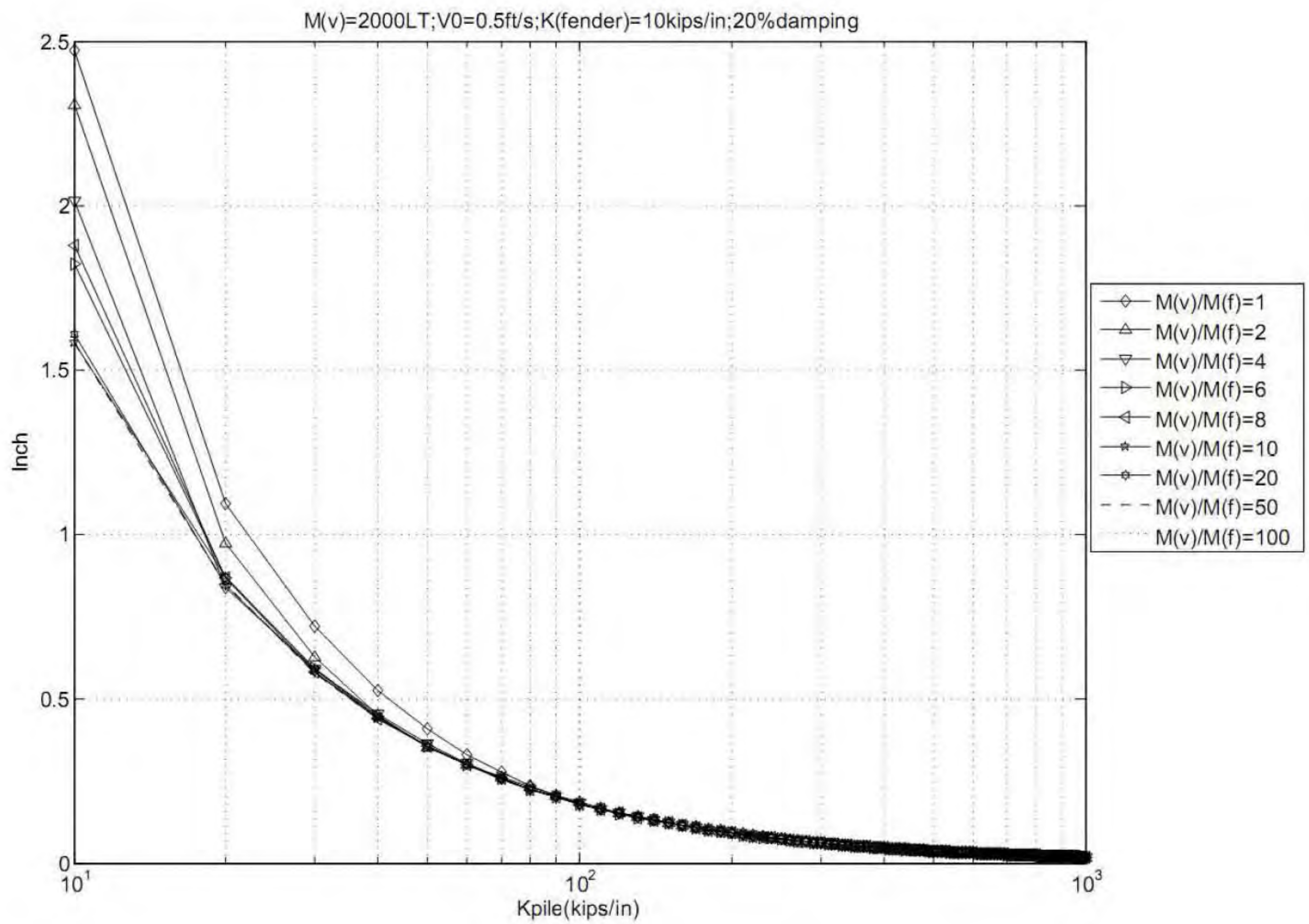


Fig. A.234 Displacement of the Piling System 2D-27b

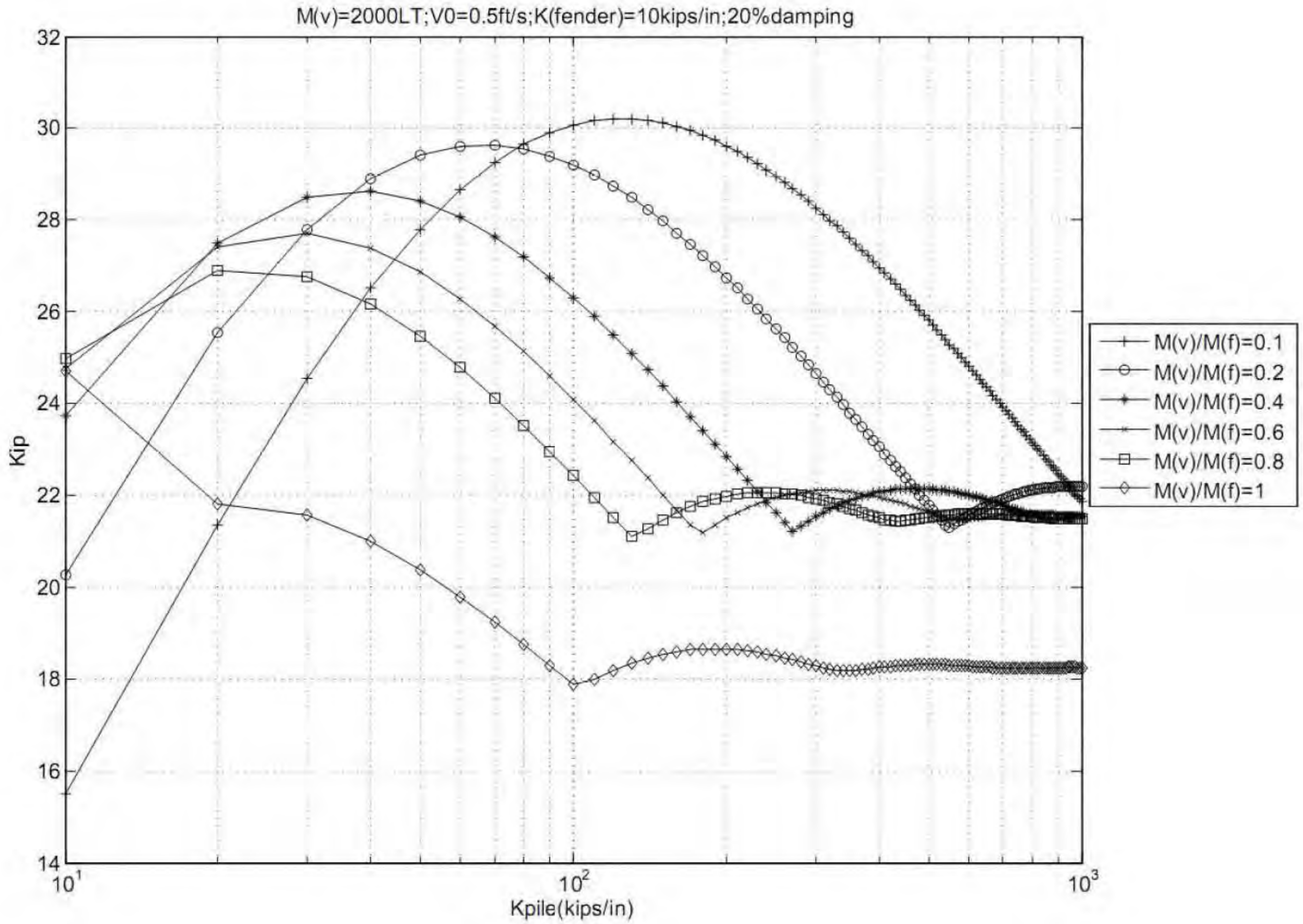


Fig. A.235 Reaction Force of the Piling System 2D-27a

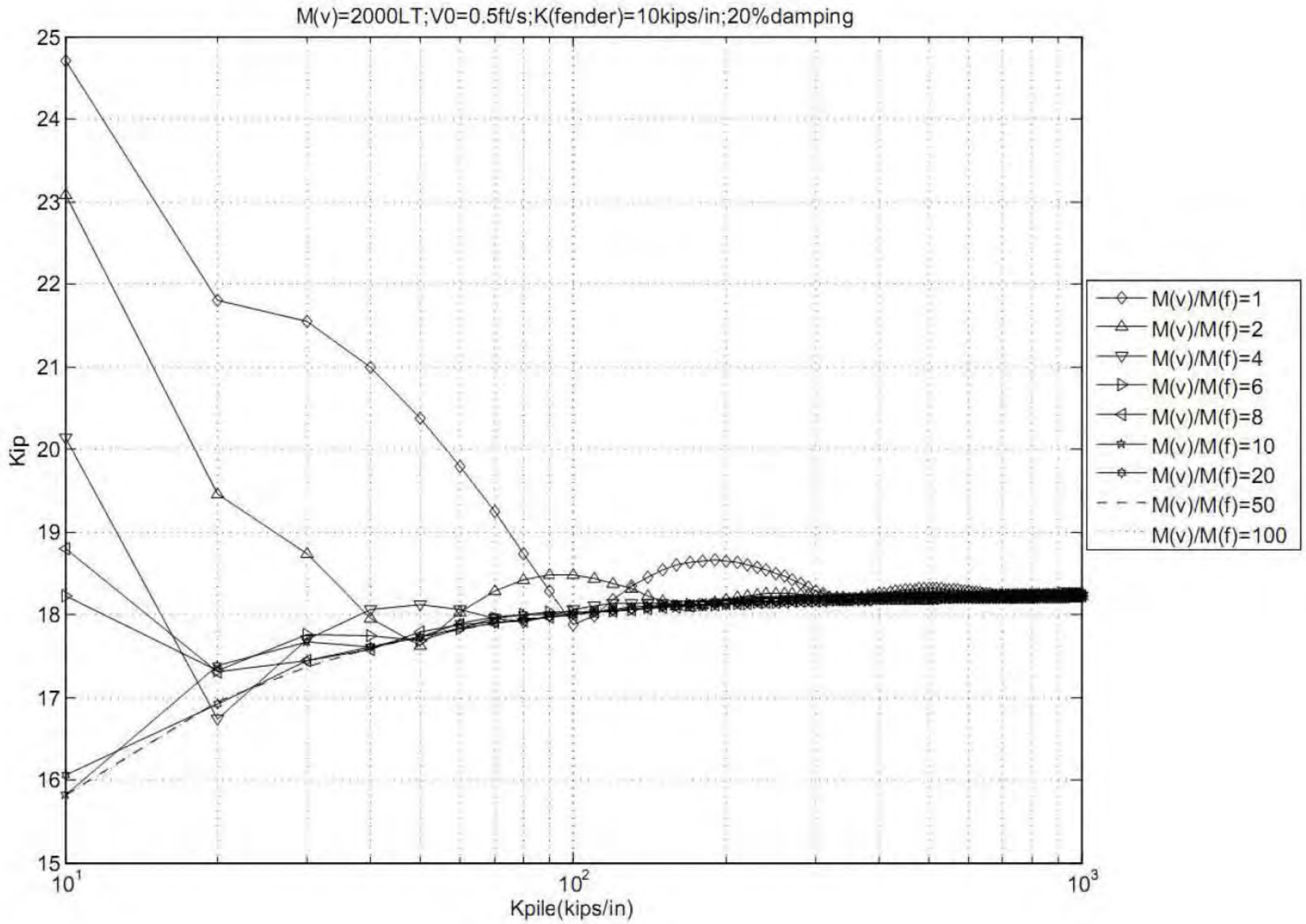


Fig. A.236 Reaction Force of the Piling System 2D-27b

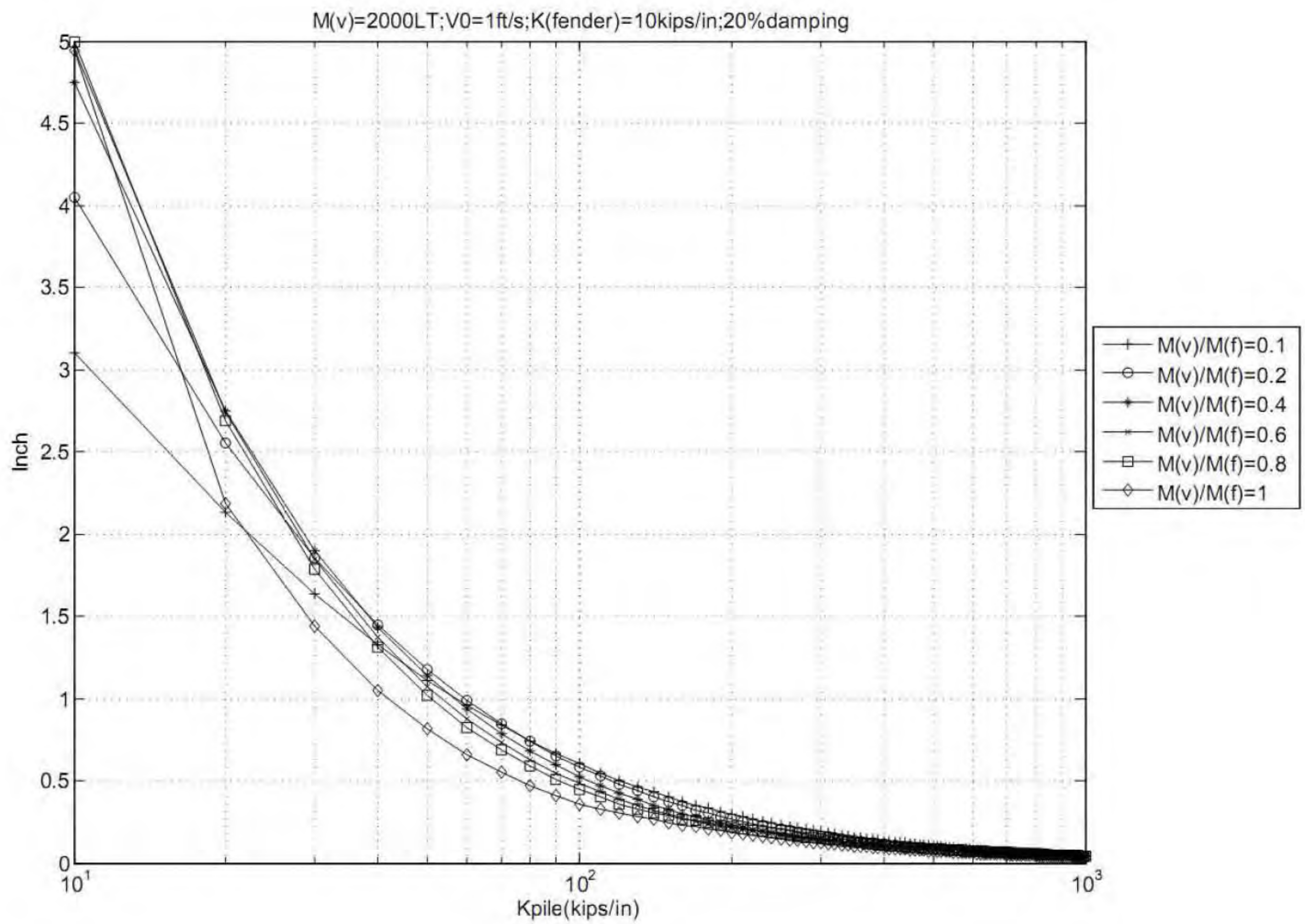


Fig. A.237 Displacement of the Piling System 2D-28a

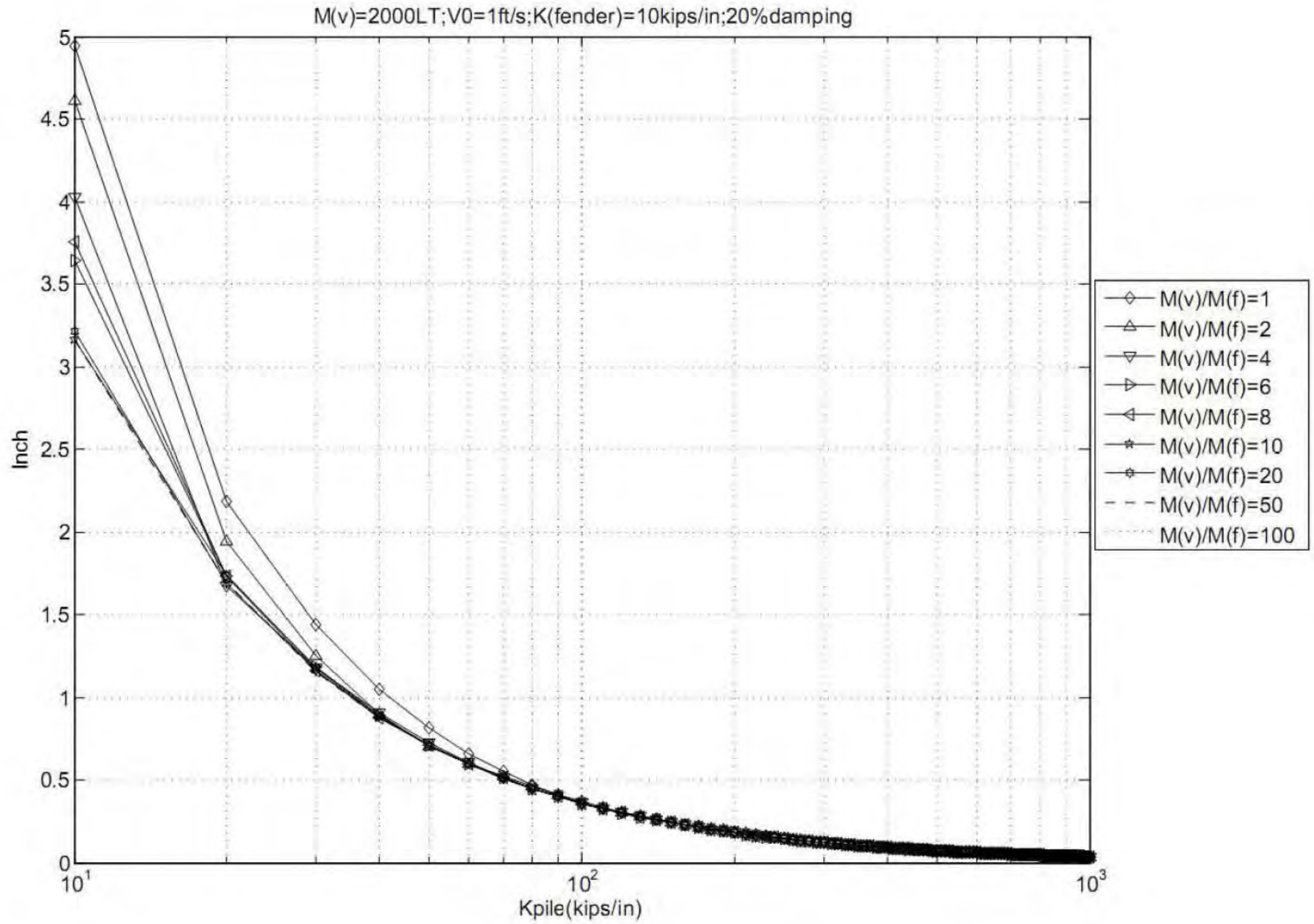


Fig. A.238 Displacement of the Piling System 2D-28b

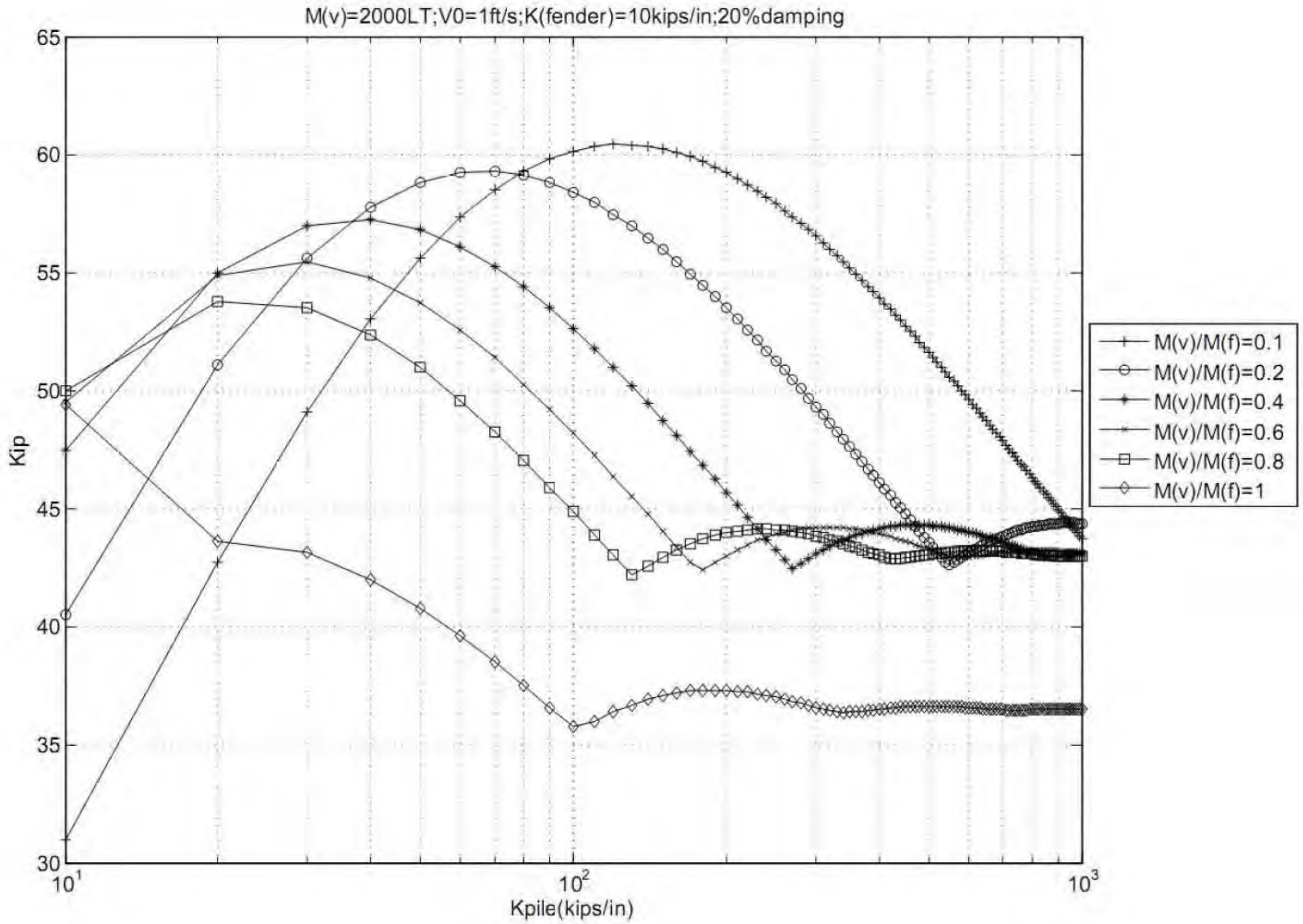


Fig. A.239 Reaction Force of the Piling System 2D-28a

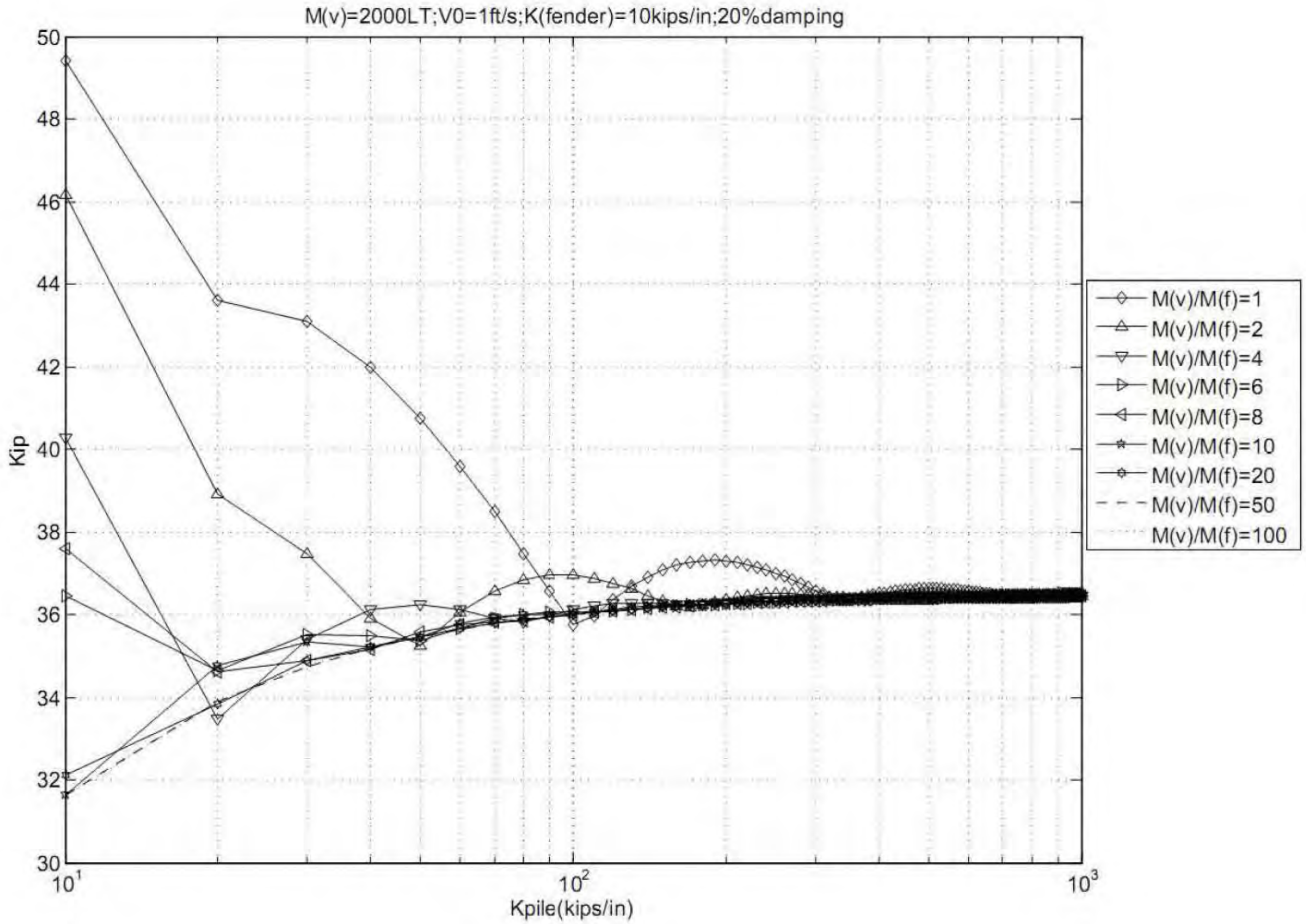


Fig. A.240 Reaction Force of the Piling System 2D-28b

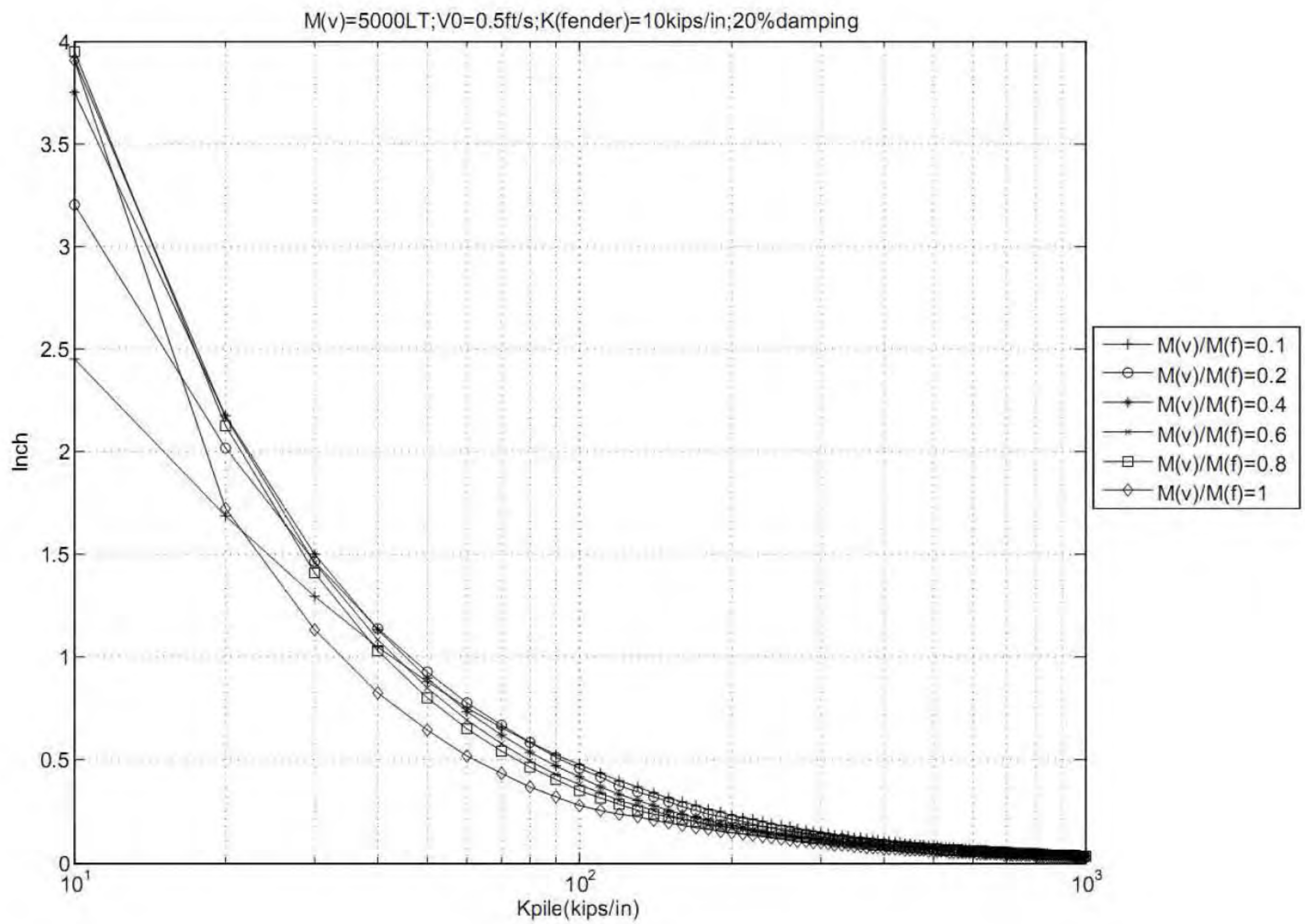


Fig. A.241 Displacement of the Piling System 2D-29a

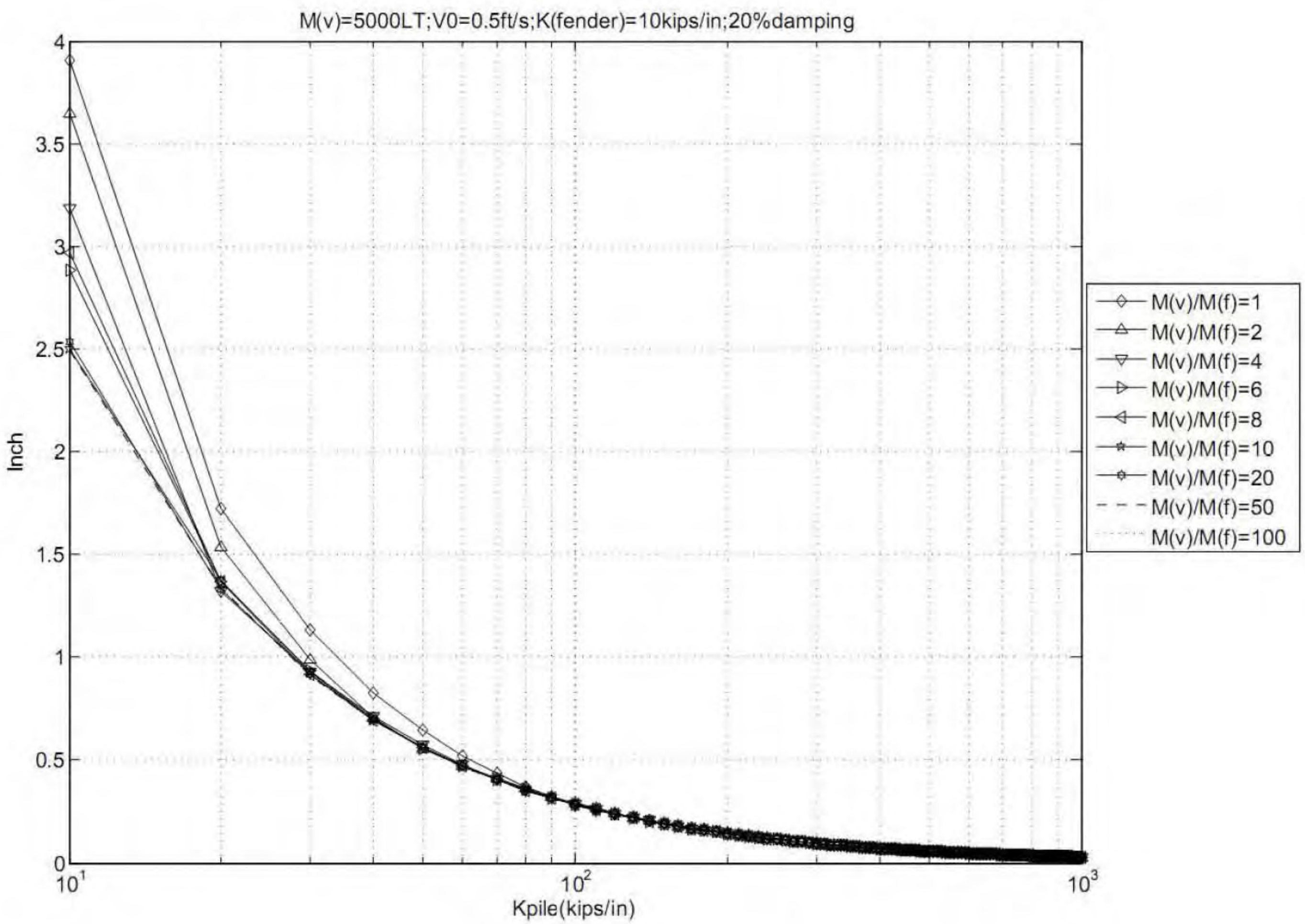


Fig. A.242 Displacement of the Piling System 2D-29b

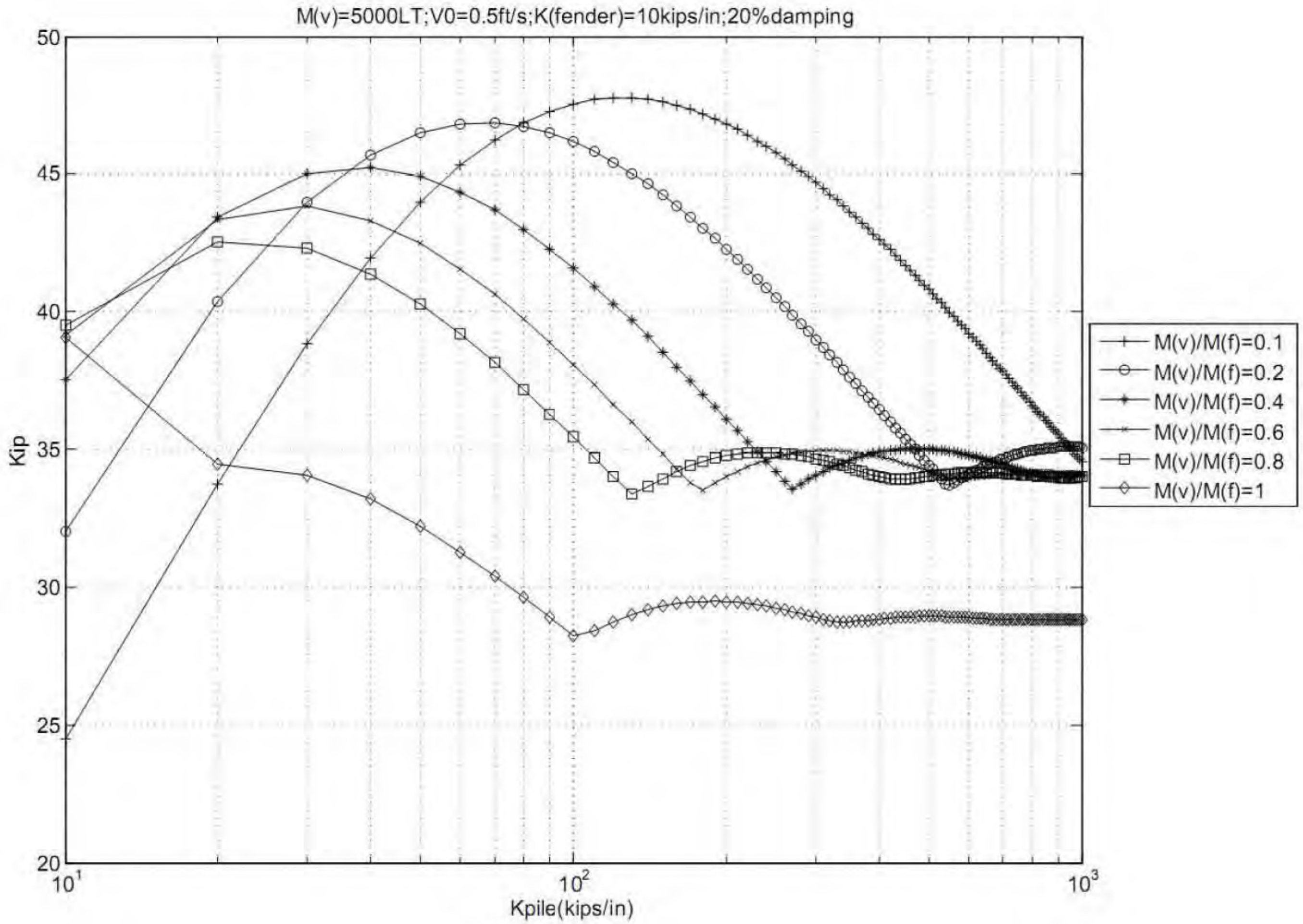


Fig. A.243 Reaction Force of the Piling System 2D-29a

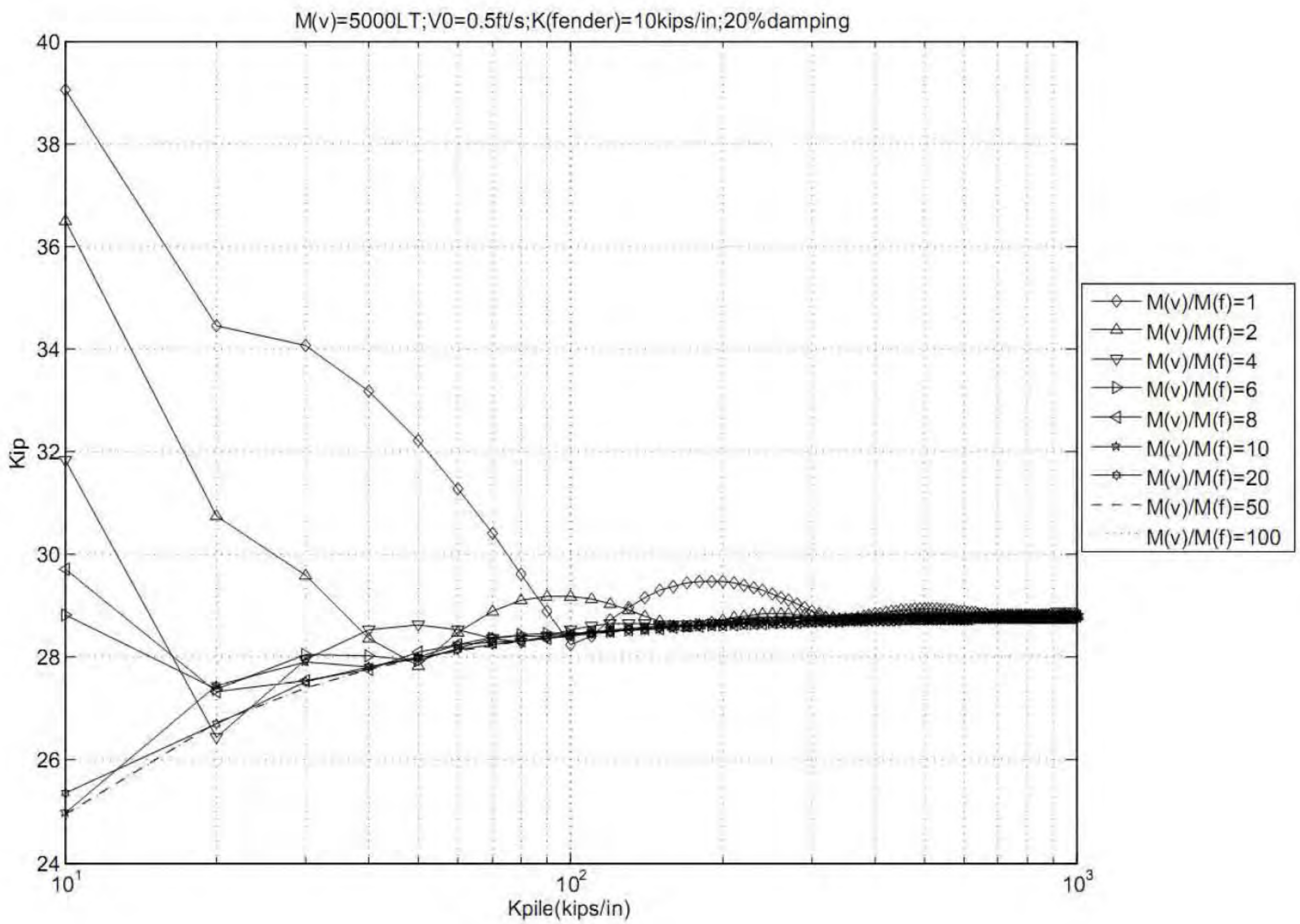


Fig. A.244 Reaction Force of the Piling System 2D-29b

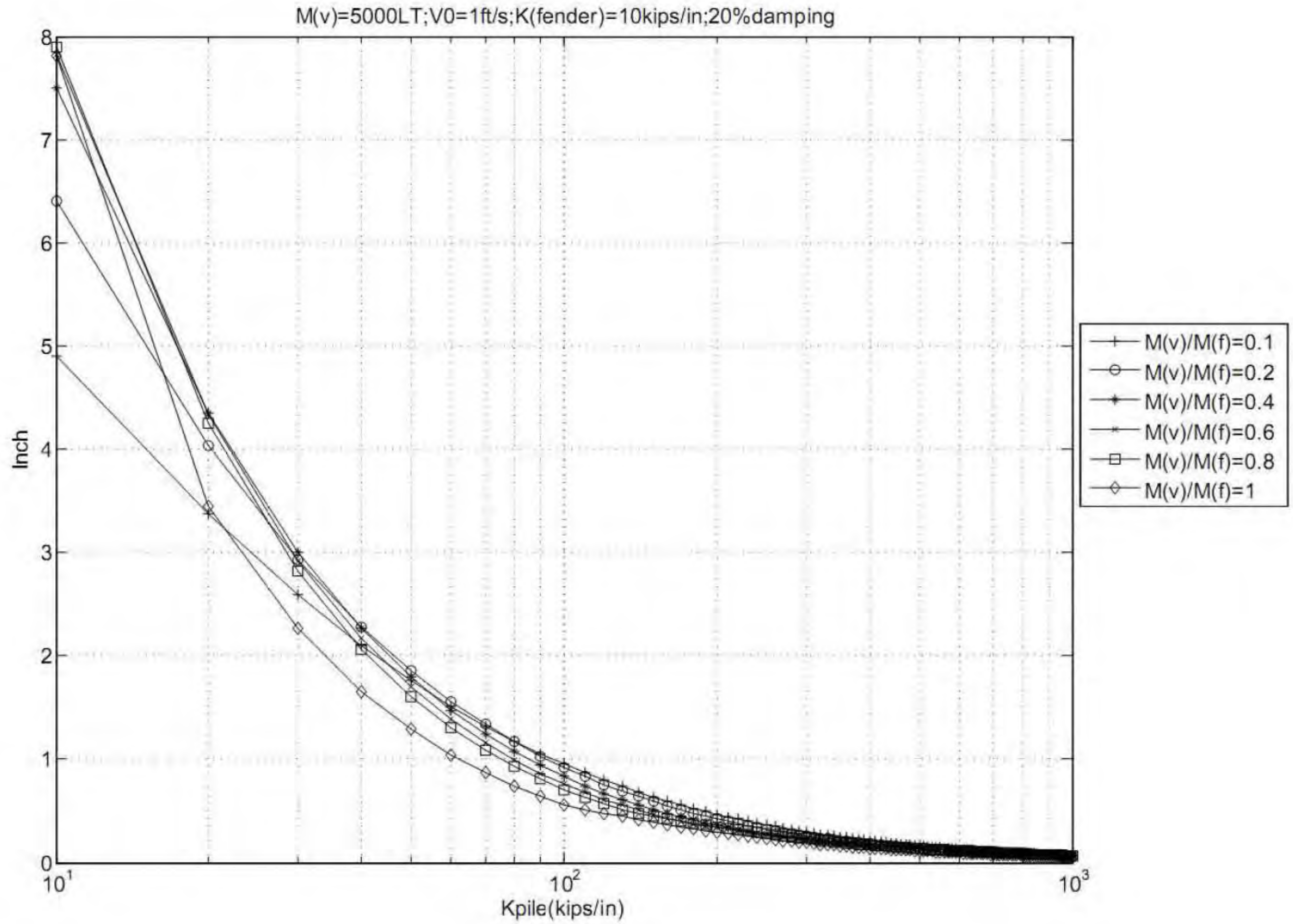


Fig. A.245 Displacement of the Piling System 2D-30a

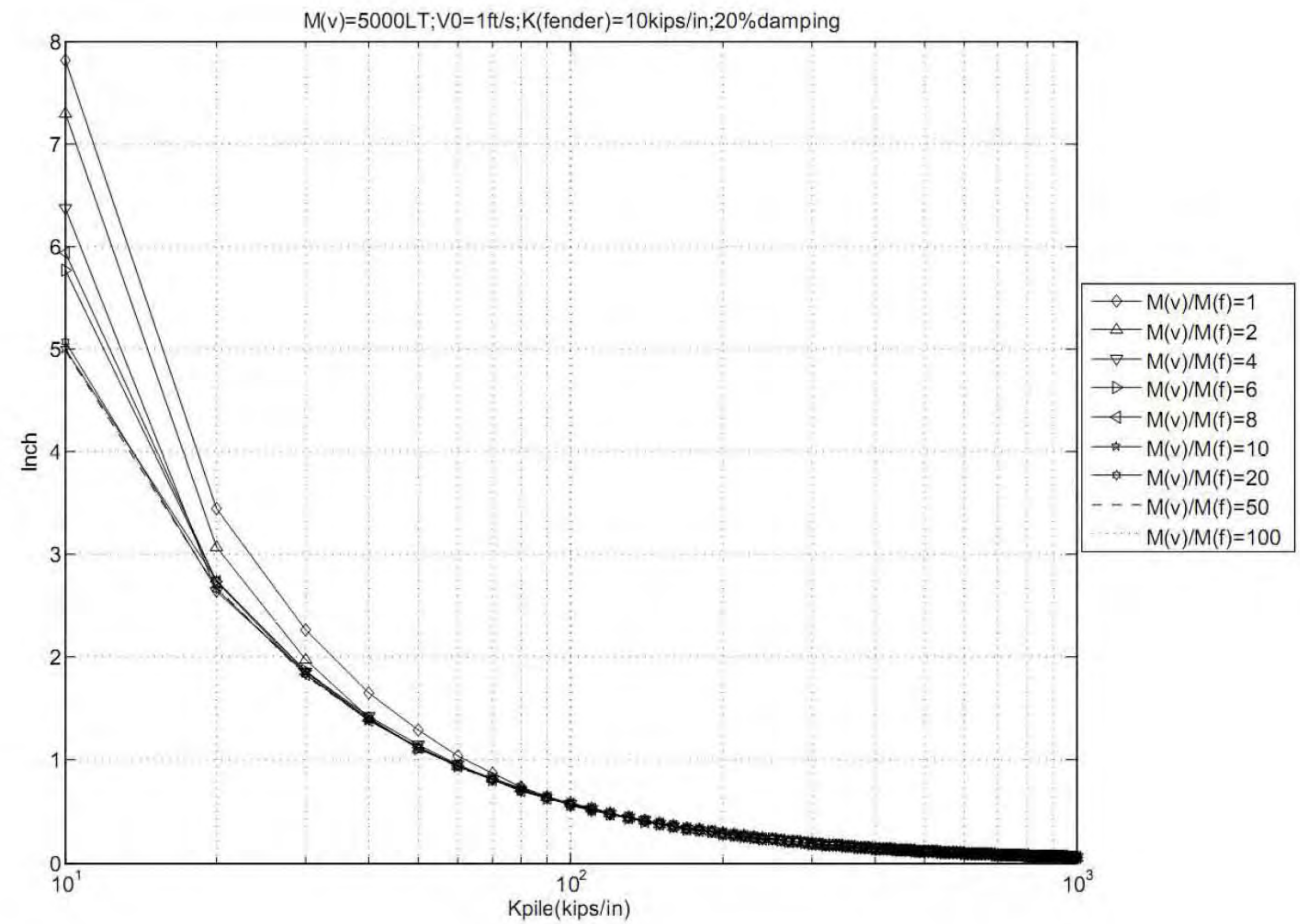


Fig. A.246 Displacement of the Piling System 2D-30b

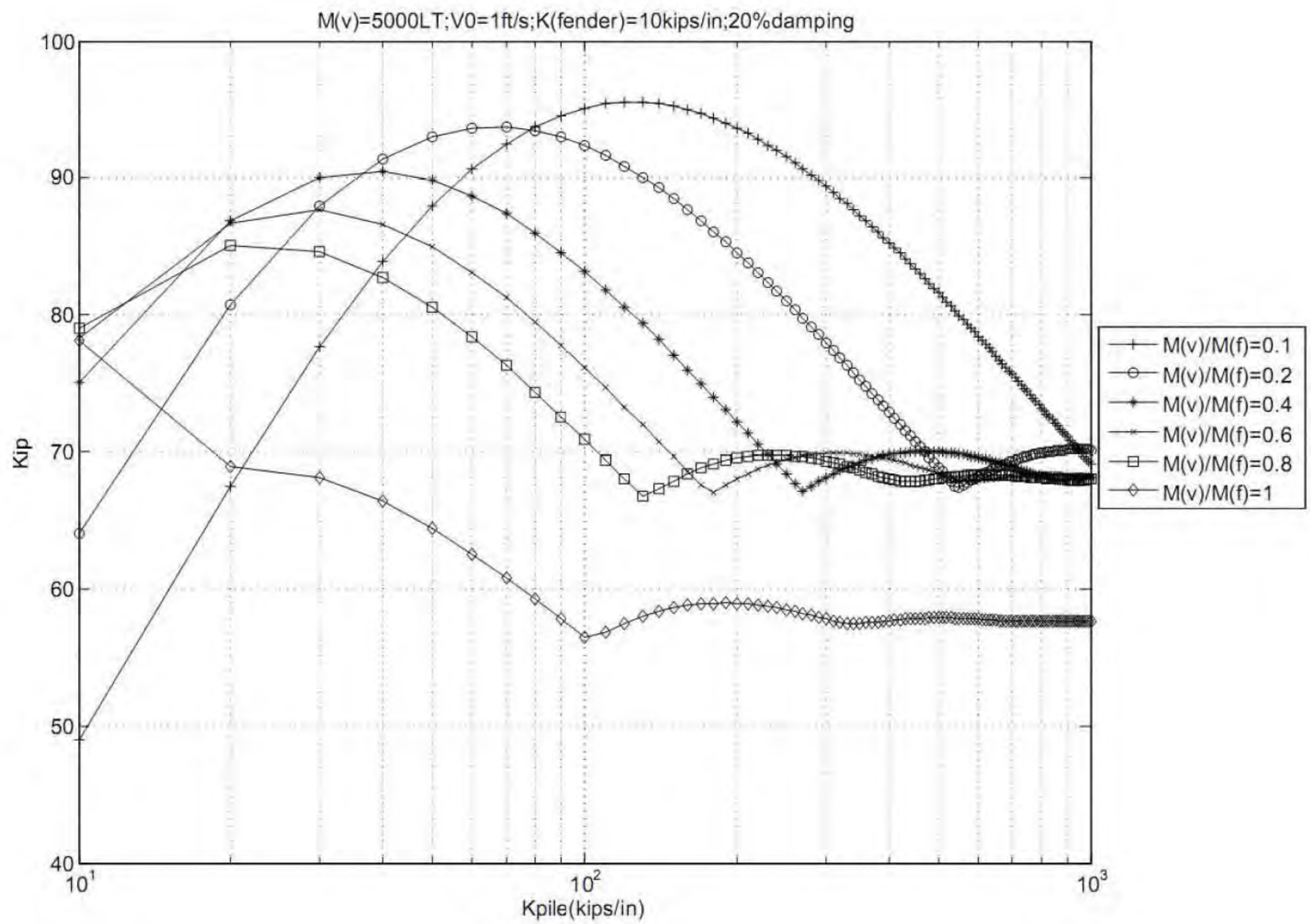


Fig. A.247 Reaction Force of the Piling System 2D-30a

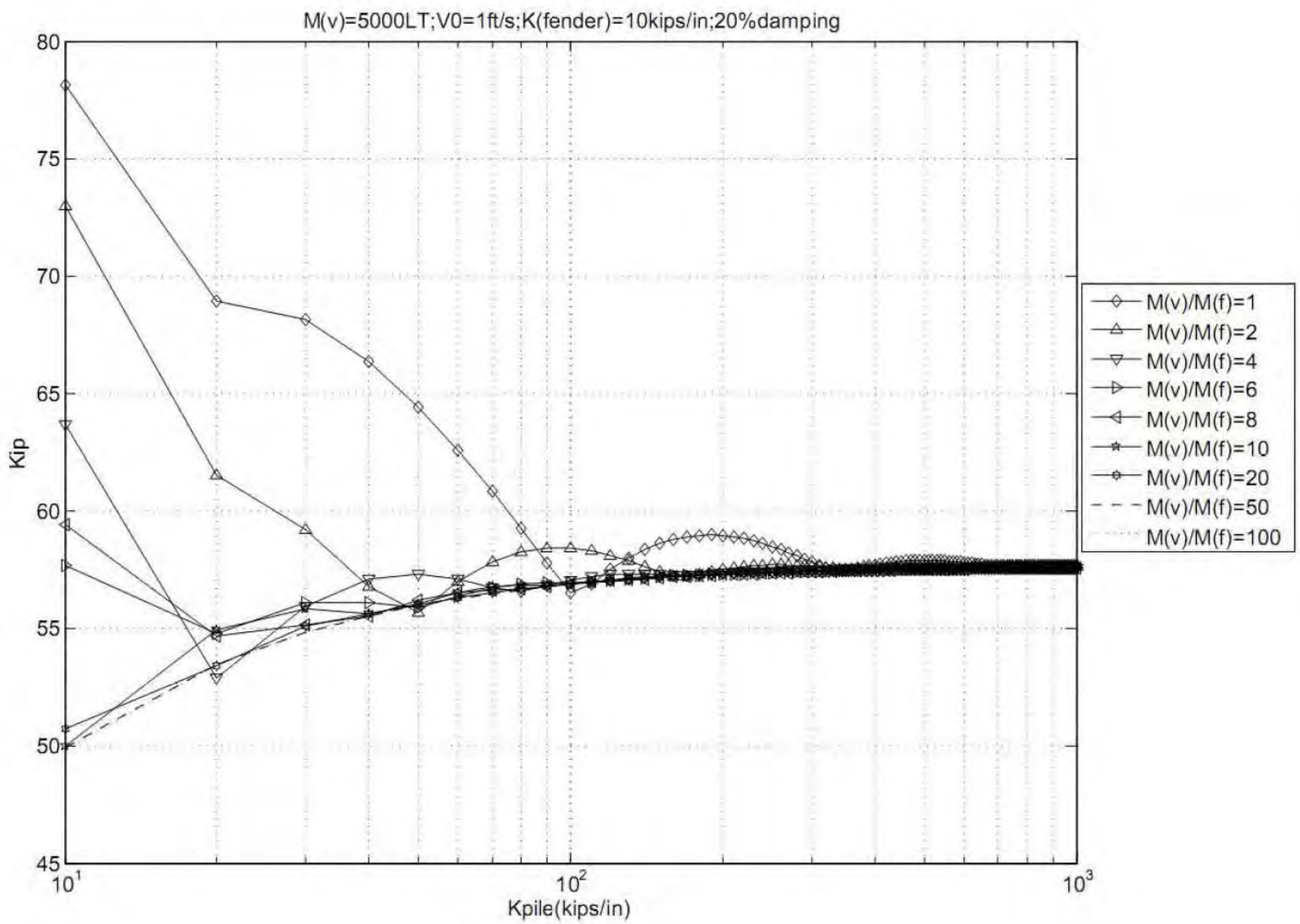


Fig. A.248 Reaction Force of the Piling System 2D-30b

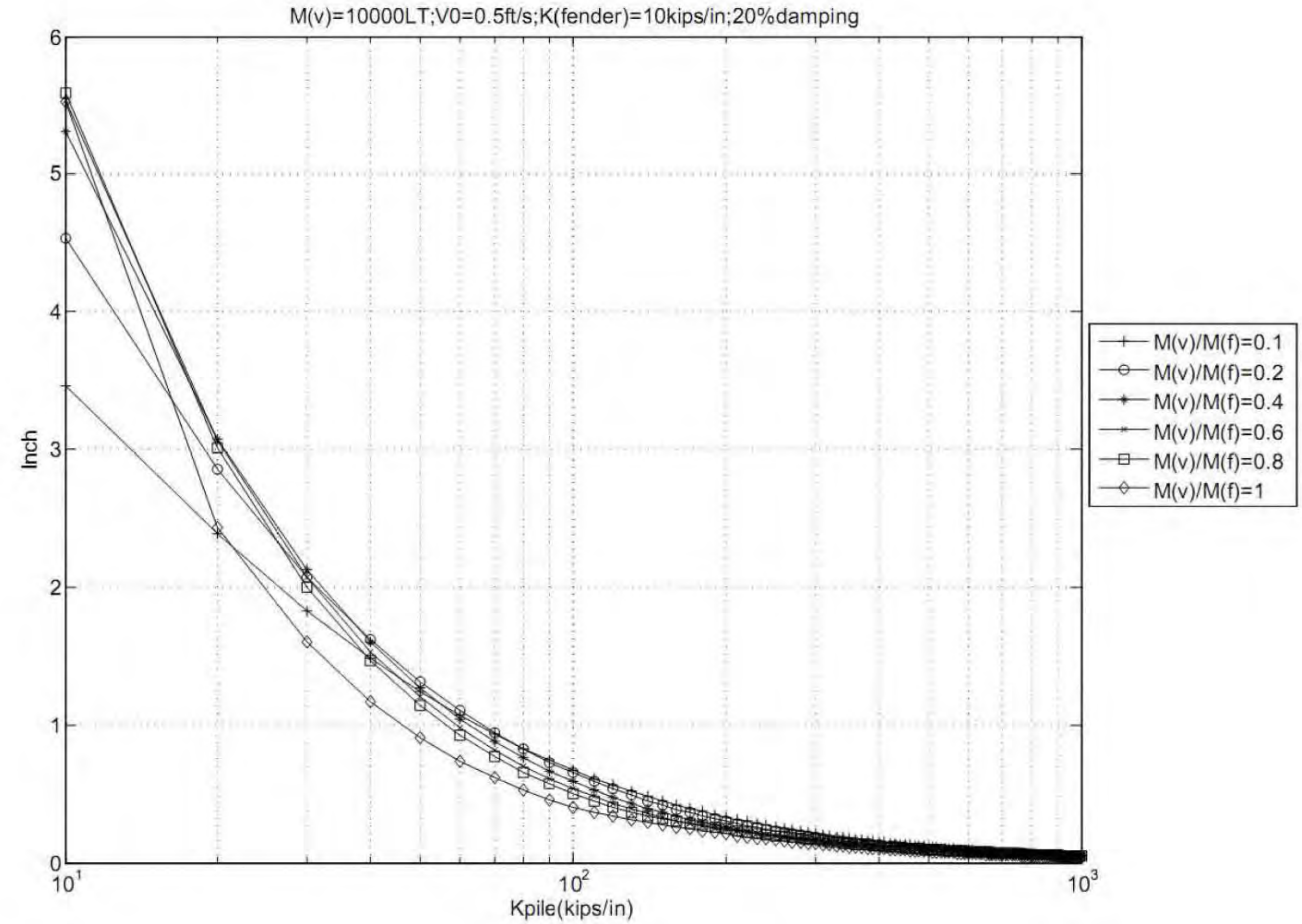


Fig. A.249 Displacement of the Piling System 2D-31a

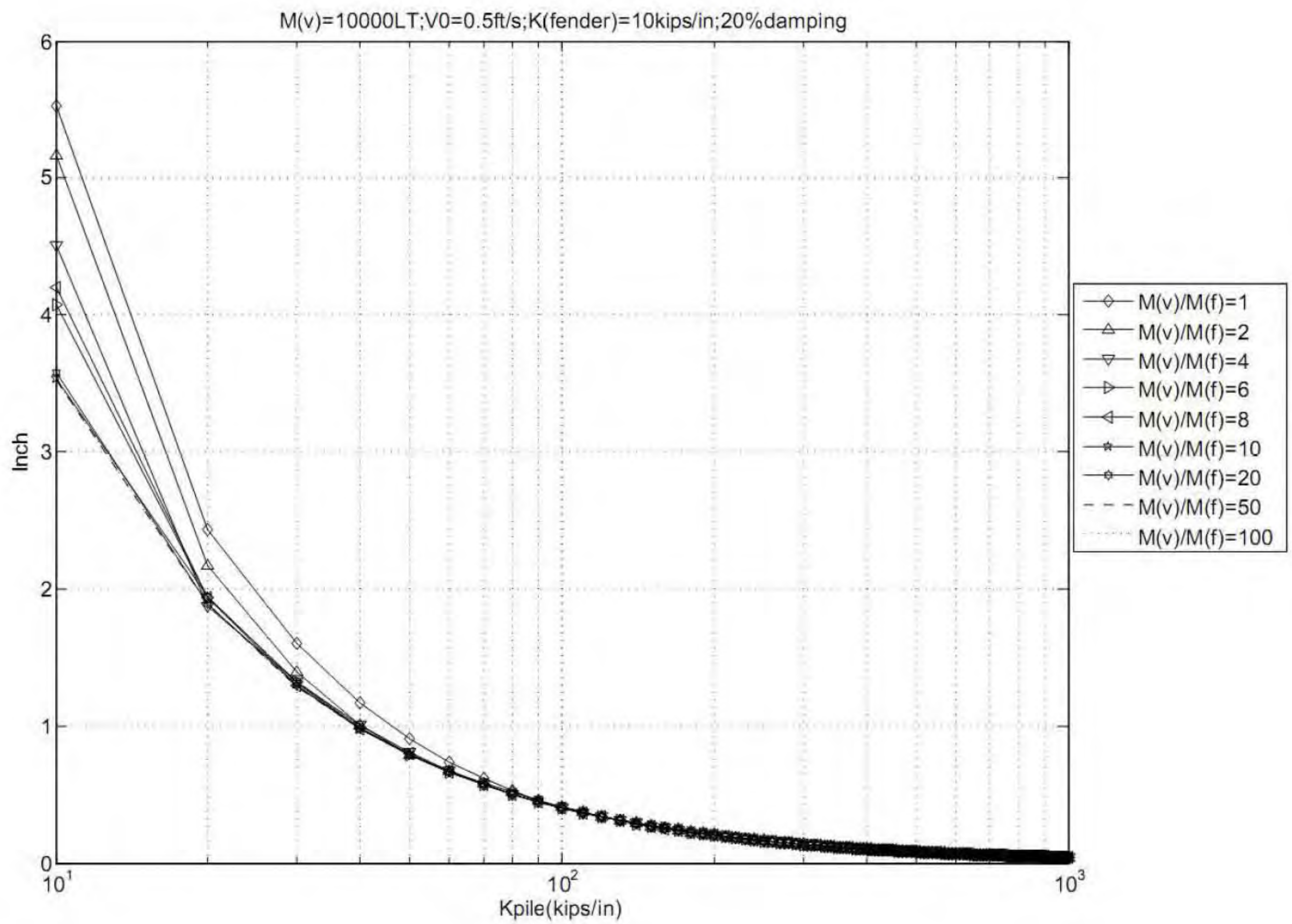


Fig. A.250 Displacement of the Piling System 2D-31b

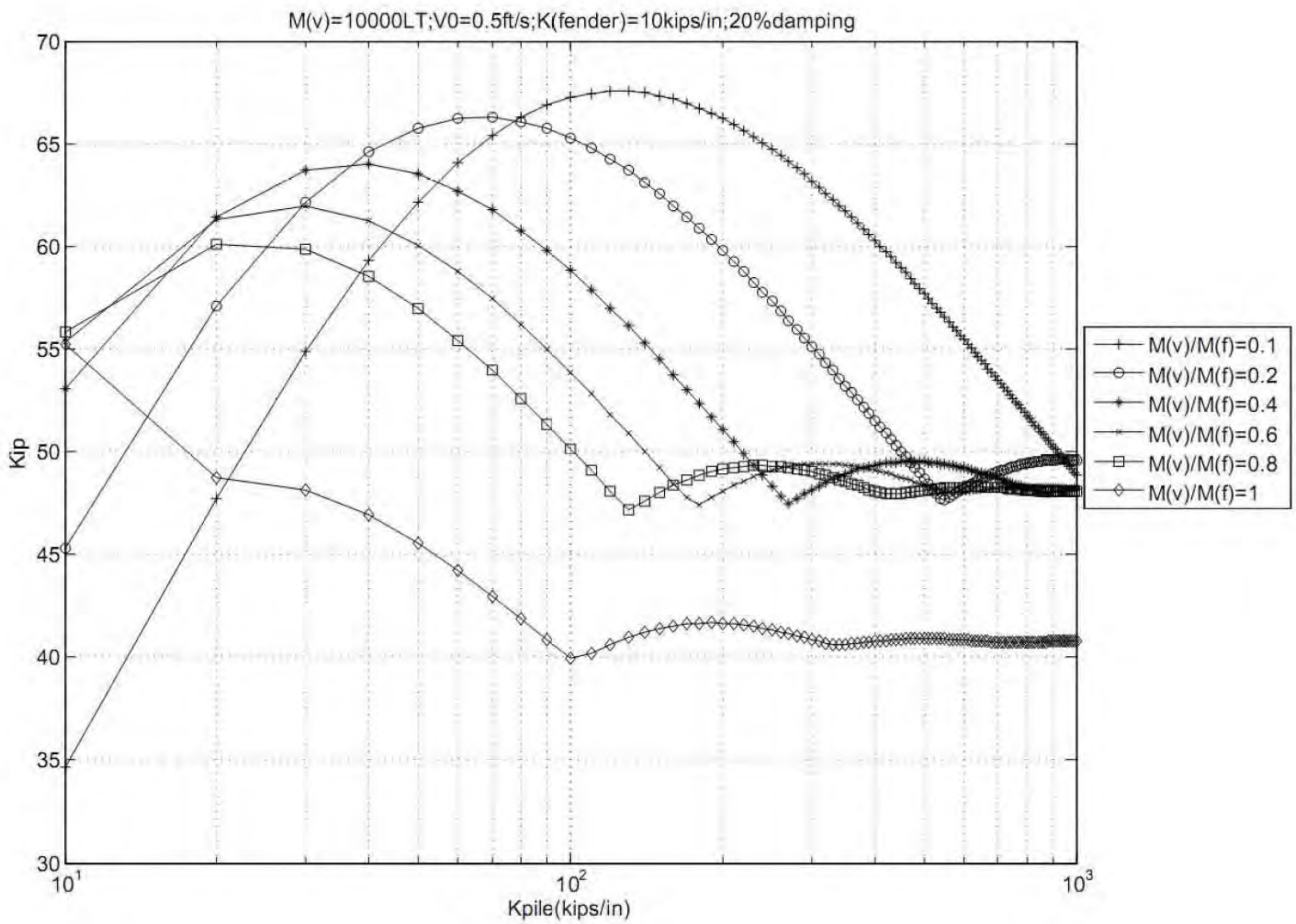


Fig. A.251 Reaction Force of the Piling System 2D-31a

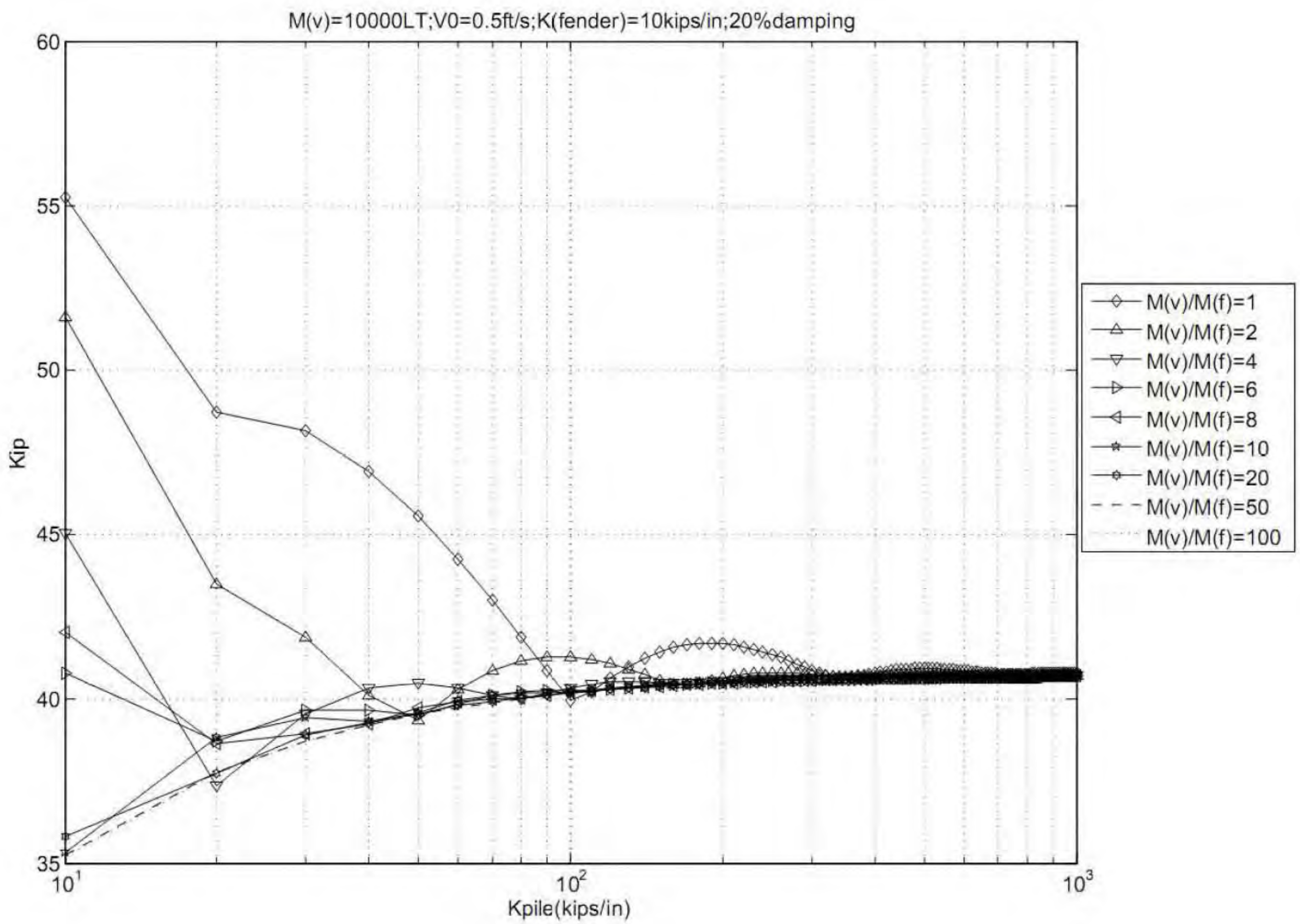


Fig. A.252 Reaction Force of the Piling System 2D-31b

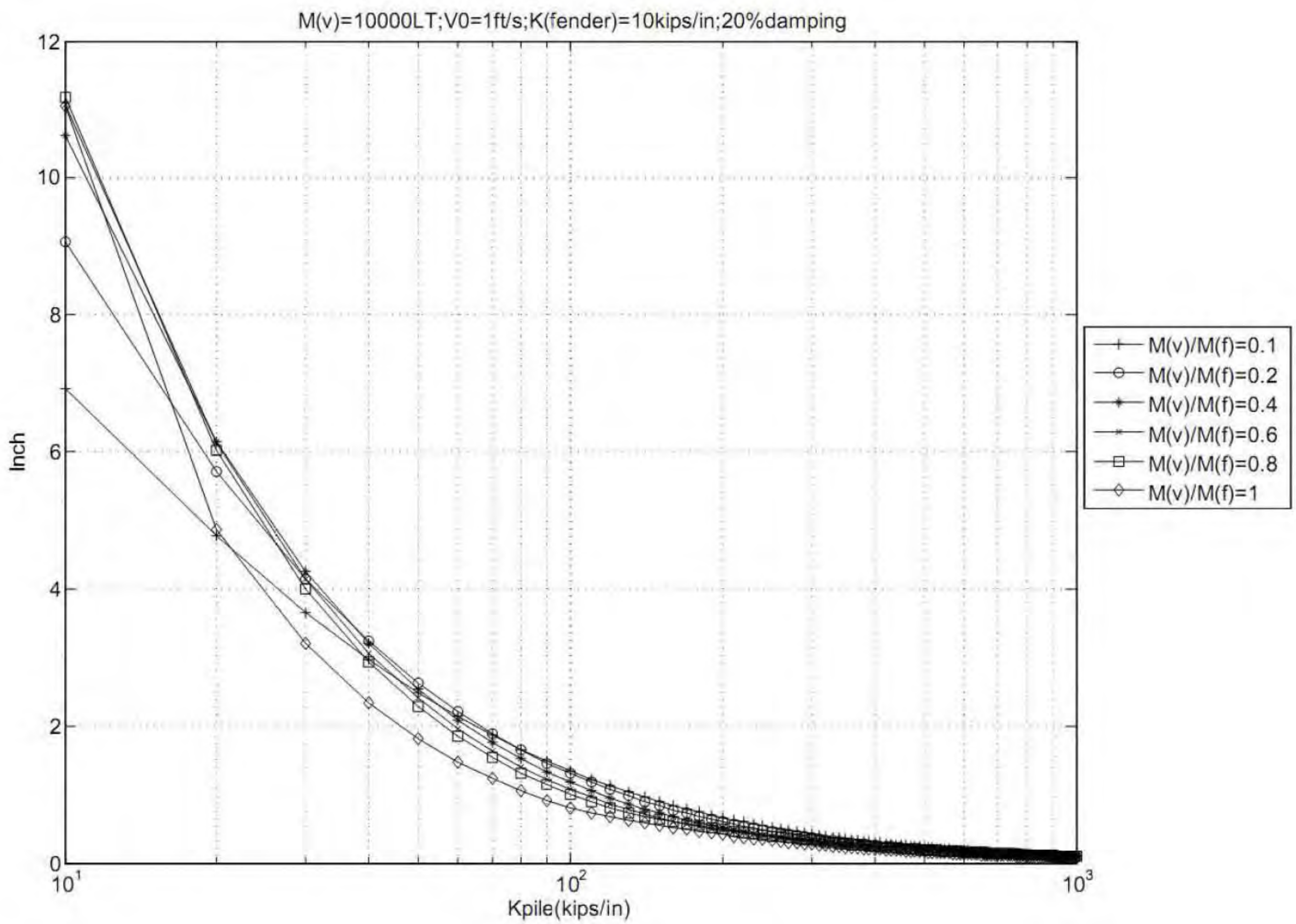


Fig. A.253 Displacement of the Piling System 2D-32a

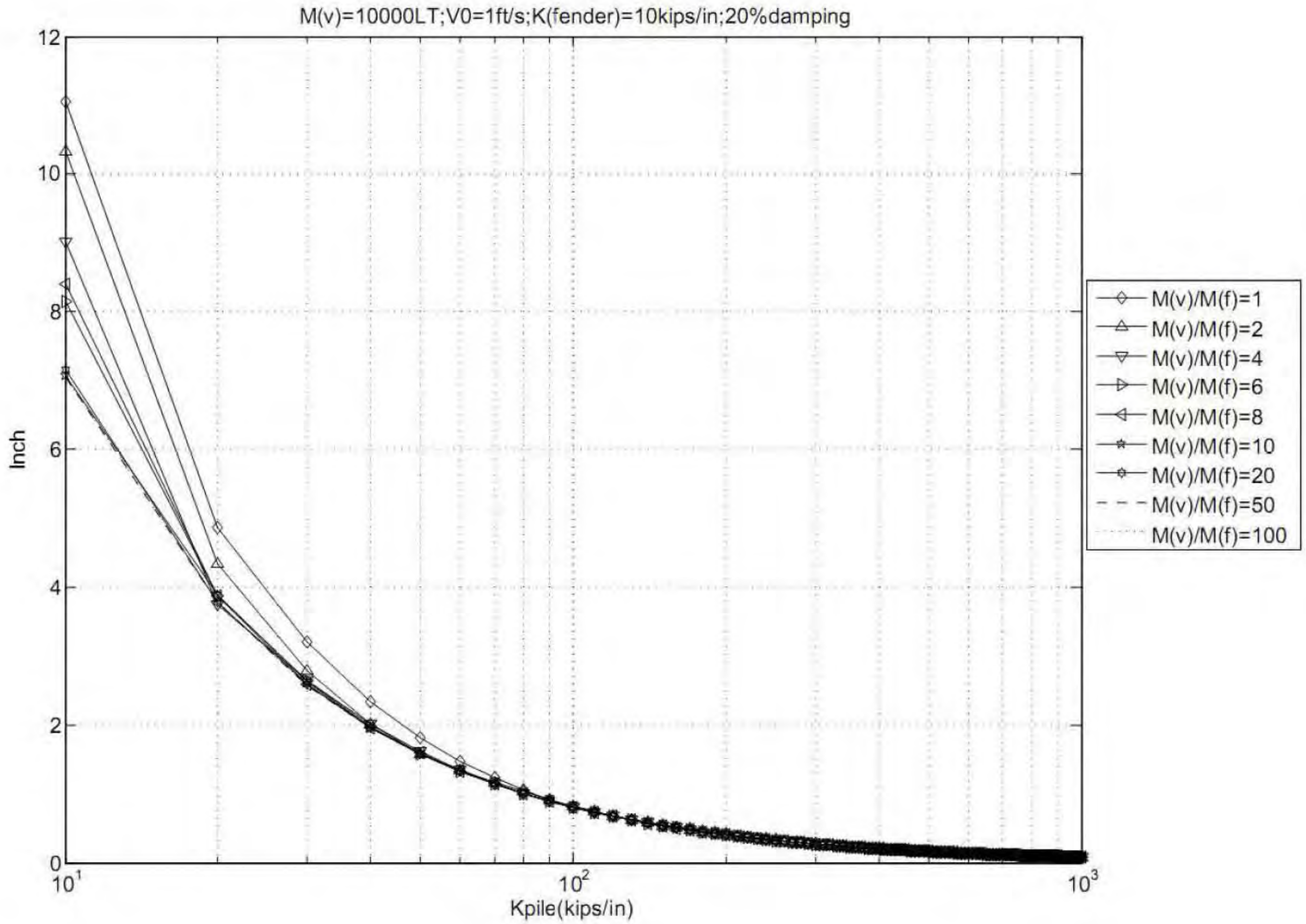


Fig. A.254 Displacement of the Piling System 2D-32b

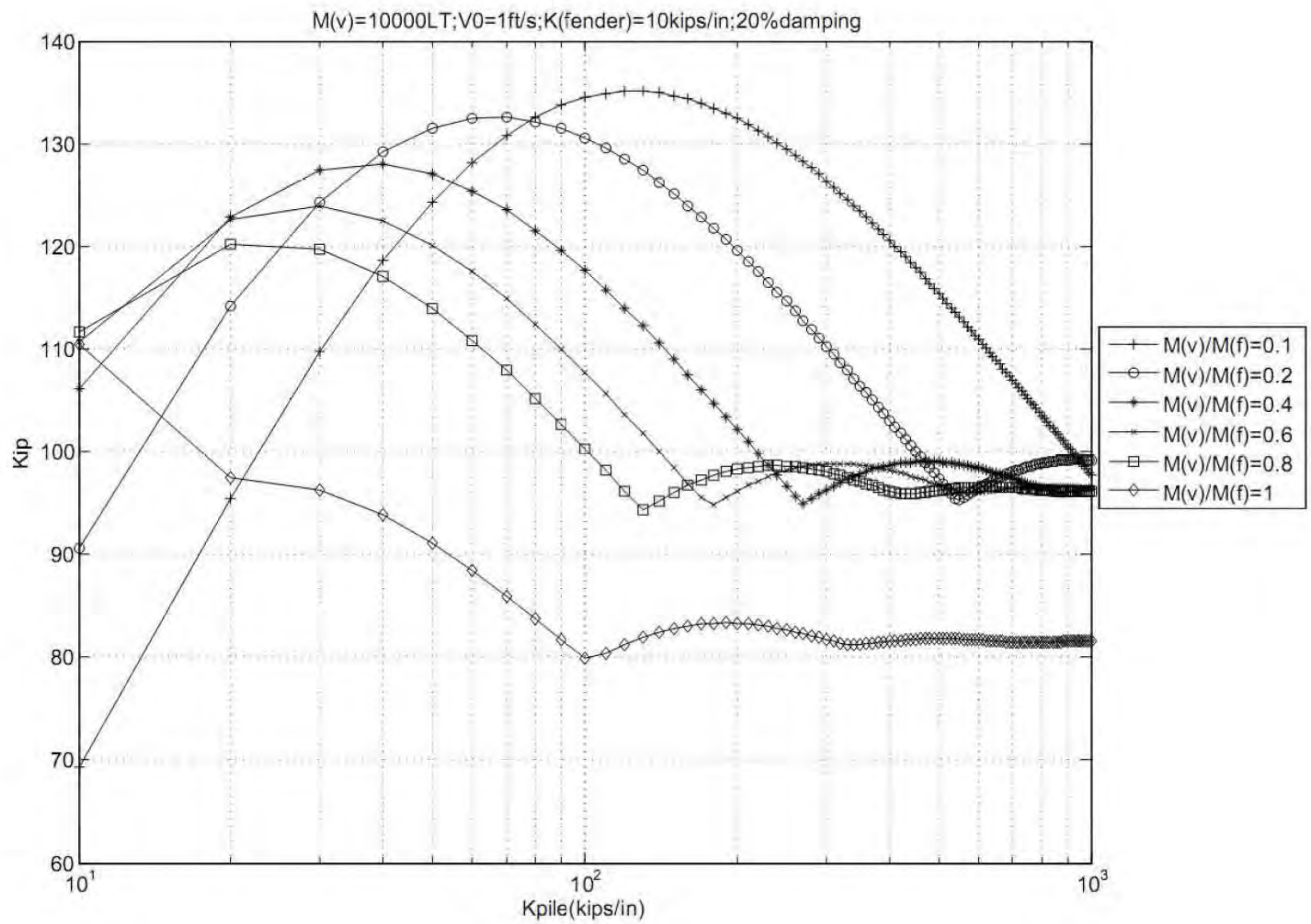


Fig. A.255 Reaction Force of the Piling System 2D-32a

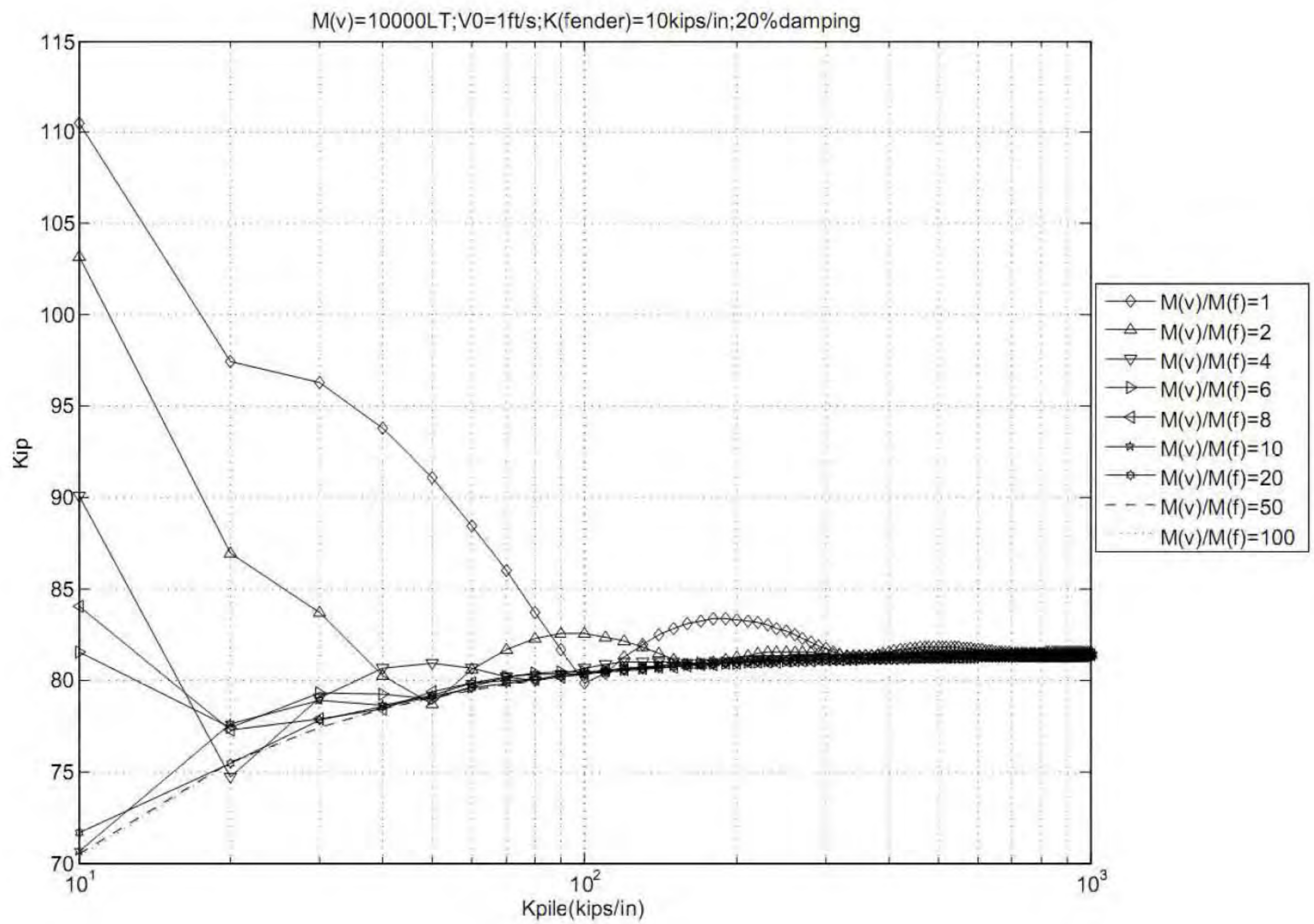


Fig. A.256 Reaction Force of the Piling System 2D-32b