In [ ]:

```python
#######################################################################################################
#                                         IN THE NAME OF ALLAH                                        #
#               Dynamic Response Analysis of Single-degree-of-freedom (SDOF) damped system            #
#                                  subjected to harmonic loading using OpenSees                       #
#  and evaluates its time-history behavior, response factors and transmissibility for harmonic excitation #
#-----------------------------------------------------------------------------------------------------#
#                            THIS PROGRAM IS WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)            #
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#######################################################################################################
```
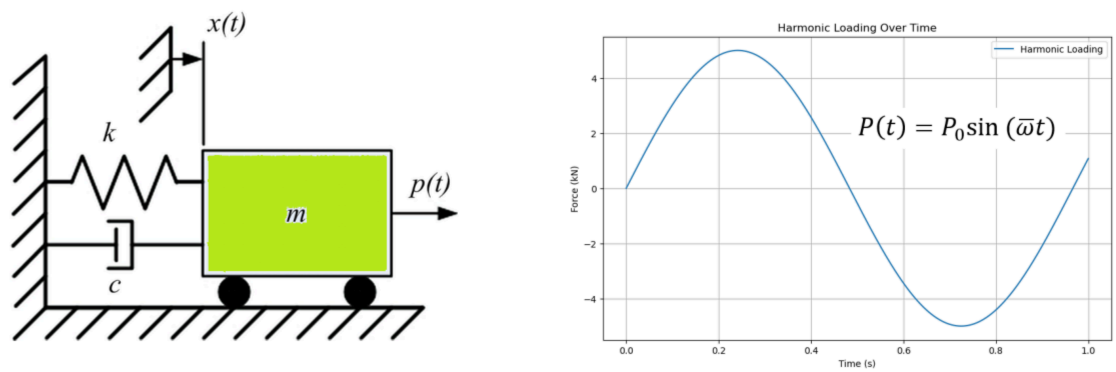

In [1]:

```python
# Load the image
def PLOT_IMAGE(image):
    import matplotlib.pyplot as plt
    import matplotlib.image as mpimg
    image = mpimg.imread(image_path)

    # Display the image
    plt.figure(figsize=(15, 8))
    plt.imshow(image)
    plt.axis('off')  # Hide axes
    plt.show()

image_path = 'OPENSEES_HARMONIC_LAODING.png'
PLOT_IMAGE(image_path)
```



In [2]:

```python
"""
Key points:
1. System Parameters: The mass, stiffness, and natural frequency of the system are defined, along with a range of damping ratios for analysis.
2. Response Factor Calculation: For 10 damping ratios, the deformation, velocity, and acceleration response factors are computed analytically over a range of excitation frequency ratio
3. Harmonic Loading: A sinusoidal force with a specified frequency and amplitude is applied as external excitation.
4. OpenSees Model: Nodes, mass, stiffness, and Rayleigh damping are defined, enabling transient analysis for time-history response.
5. Time History Simulation: The system's displacement, velocity, acceleration, and base reactions are simulated over a defined time span.
6. Harmonic Force Visualization: The applied harmonic force is plotted over time.
7. Time History Results: Displacement, velocity, acceleration, and base reaction time histories are plotted to illustrate transient response.
8. Analysis Insights: The code evaluates system behavior under various damping conditions and external forcing scenarios.
9. Visual Representation: Comprehensive plots provide insights into both steady-state and transient behaviors of the damped SDOF system.
10. Plotting: Response factors (deformation, velocity, acceleration) are plotted against frequency ratios for different damping ratios.
11. Plotting: Transmissibility for harmonic excitation. Force transmissibility and ground motion transmissibility
"""
import openseespy.opensees as ops
import numpy as np
import matplotlib.pyplot as plt

# System parameters
mass = 10.0          # Mass (ton)
stiffness = 100.0  # Stiffness (kN/m)
omega_n = np.sqrt(stiffness / mass)  # Natural angular frequency (rad/s)

# Define the OpenSees model
ops.wipe()
ops.model('Basic', '-ndm', 1, '-ndf', 1)

# Define nodes
ops.node(1, 0.0)  # Fixed node
ops.node(2, 0.0)  # Moving node

# Define boundary conditions
ops.fix(1, 1)

# Define mass
ops.mass(2, mass)

# Define spring element
ops.uniaxialMaterial('Elastic', 1, stiffness)
ops.element('zeroLength', 1, 1, 2, '-mat', 1, '-dir', 1)

# Time history analysis for a specific damping ratio
zeta = 0.05 # Damping Ratio
ops.rayleigh(0.0, 0.0, 2 * zeta * omega_n, 0.0)

dt = 0.01  # Time step
total_time = 50.0
num_steps = int(total_time / dt)
force_time = np.linspace(0, 0.1 * total_time, num_steps) # Force time 10 is percent of total time

target_frequency = 0.65 * omega_n  # Target excitation frequency
force_amplitude = 5.0
force = force_amplitude * np.sin(target_frequency * force_time)

# Plot harmonic loading
plt.figure(figsize=(10, 6))
plt.plot(force_time, force, label='Harmonic Loading')
plt.title('Harmonic Loading Over Time')
plt.xlabel('Time (s)')
plt.ylabel('Force (kN)')
```

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plt.grid(True)
plt.legend()
plt.show()

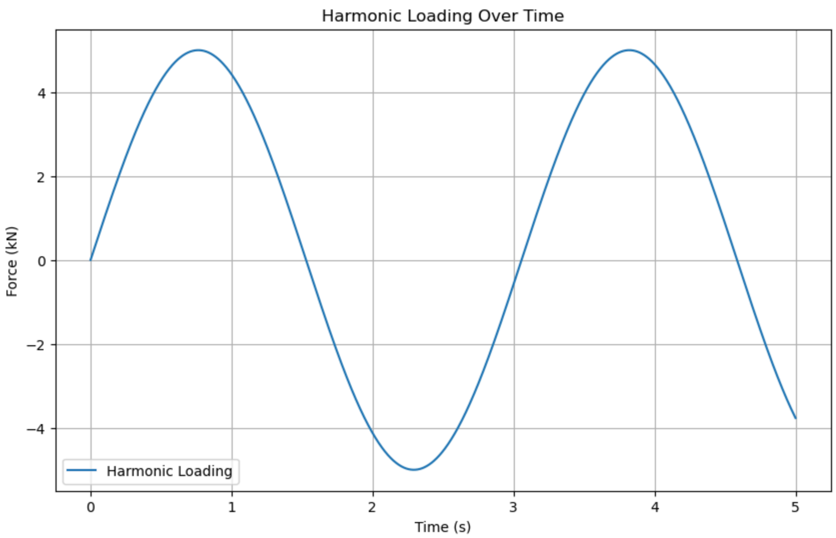
# Apply force time series
ops.timeSeries('Path', 1, '-dt', dt, '-values', *force)
ops.pattern('Plain', 1, 1)
ops.load(2, 1.0)  # Apply load to moving node

# Analysis setup
ops.constraints('Transformation')
ops.numberer('RCM')
ops.system('UmfPack')
ops.test('NormDispIncr', 1.0e-8, 10)
ops.integrator('Newmark', 0.5, 0.25)
ops.algorithm('Newton')
ops.analysis('Transient')

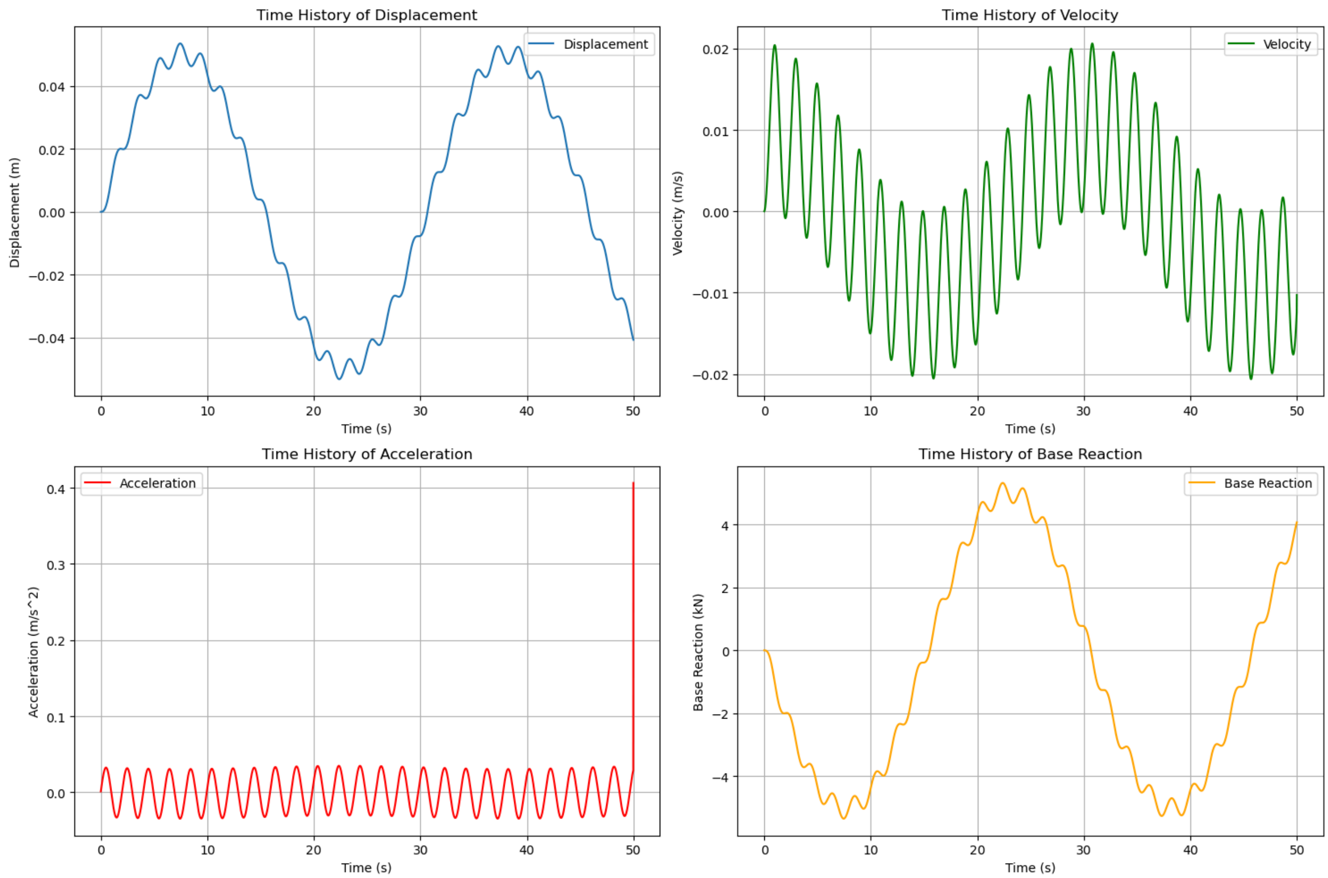
# Time history results
time_history_displacement = []
time_history_velocity = []
time_history_acceleration = []
time_history_base_reaction = []
time_history_time = []

# Perform time history analysis
for step in range(num_steps):
    ops.analyze(1, dt)
    disp = ops.nodeDisp(2, 1)
    vel = ops.nodeVel(2, 1)
    accel = ops.nodeAccel(2, 1)
    reaction = -stiffness * disp  # Base reaction

    time_history_displacement.append(disp)
    time_history_velocity.append(vel)
    time_history_acceleration.append(accel)
    time_history_base_reaction.append(reaction)
    time_history_time.append(step * dt)
```



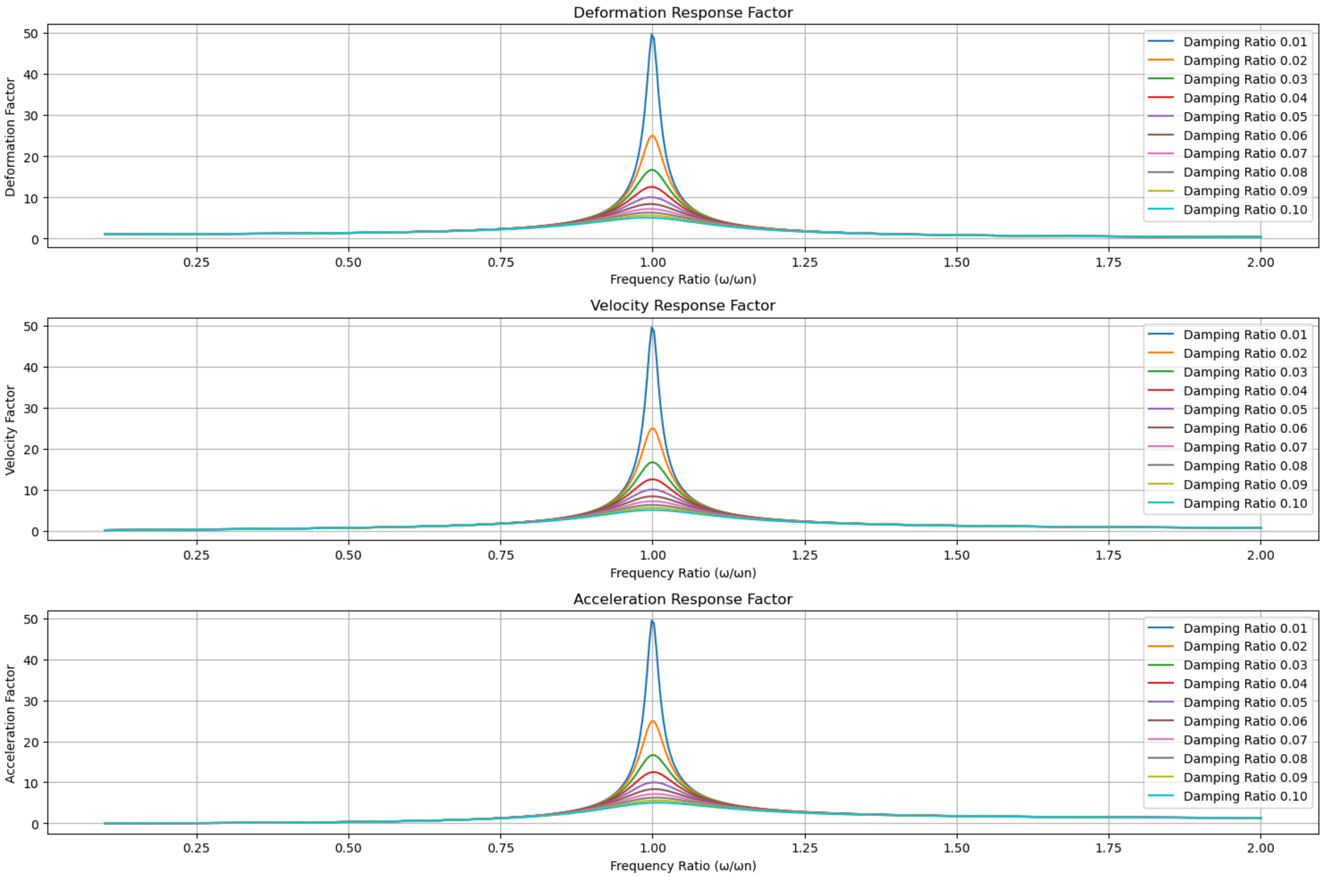
In [3]:
```python
# Plot time history results
plt.figure(figsize=(15, 10))

plt.subplot(2, 2, 1)
plt.plot(time_history_time, time_history_displacement, label='Displacement')
plt.title('Time History of Displacement')
plt.xlabel('Time (s)')
plt.ylabel('Displacement (m)')
plt.grid(True)
plt.legend()

plt.subplot(2, 2, 2)
plt.plot(time_history_time, time_history_velocity, label='Velocity', color='g')
plt.title('Time History of Velocity')
plt.xlabel('Time (s)')
plt.ylabel('Velocity (m/s)')
plt.grid(True)
plt.legend()

plt.subplot(2, 2, 3)
plt.plot(time_history_time, time_history_acceleration, label='Acceleration', color='r')
plt.title('Time History of Acceleration')
plt.xlabel('Time (s)')
plt.ylabel('Acceleration (m/s^2)')
plt.grid(True)
plt.legend()

plt.subplot(2, 2, 4)
plt.plot(time_history_time, time_history_base_reaction, label='Base Reaction', color='orange')
plt.title('Time History of Base Reaction')
plt.xlabel('Time (s)')
plt.ylabel('Base Reaction (kN)')
plt.grid(True)
plt.legend()

plt.tight_layout()
plt.show()
```



In [5]:

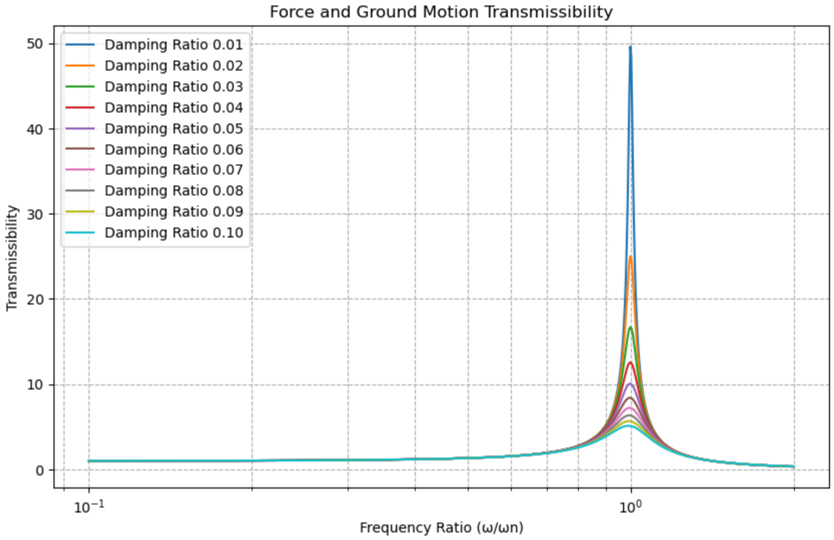
```python
# Damping ratios to evaluate
damping_ratios = np.linspace(0.01, 0.1, 10)  # 10 damping ratios between 0.01 and 0.1

# Harmonic excitation
frequency_ratios = np.linspace(0.1, 2.0, 500)  # Excitation frequency ratios (omega / omega_n)

# Storage for response factors
response_factors_deformation = []
response_factors_velocity = []
response_factors_acceleration = []

# Loop over damping ratios
for zeta in damping_ratios:
    # Define Rayleigh damping
    ops.rayleigh(0.0, 0.0, 2 * zeta * omega_n, 0.0)

    deformation_factors = []
    velocity_factors = []
    acceleration_factors = []

    # Loop over frequency ratios
    for r in frequency_ratios:
        omega_excitation = r * omega_n

        # Response factor formulas
        denominator = np.sqrt((1 - r**2)**2 + (2 * zeta * r)**2)
        deformation_factors.append(1 / denominator)
        velocity_factors.append(r / denominator)
        acceleration_factors.append(r**2 / denominator)

    response_factors_deformation.append(deformation_factors)
    response_factors_velocity.append(velocity_factors)
    response_factors_acceleration.append(acceleration_factors)

# Plot response factors
plt.figure(figsize=(15, 10))

plt.subplot(3, 1, 1)
for i, zeta in enumerate(damping_ratios):
    plt.plot(frequency_ratios, response_factors_deformation[i], label=f'Damping Ratio {zeta:.2f}')
plt.title('Deformation Response Factor')
plt.xlabel('Frequency Ratio (\u03c9/\u03c9n)')
plt.ylabel('Deformation Factor')
plt.legend()
plt.grid(True)

plt.subplot(3, 1, 2)
for i, zeta in enumerate(damping_ratios):
    plt.plot(frequency_ratios, response_factors_velocity[i], label=f'Damping Ratio {zeta:.2f}')
plt.title('Velocity Response Factor')
plt.xlabel('Frequency Ratio (\u03c9/\u03c9n)')
plt.ylabel('Velocity Factor')
plt.legend()
plt.grid(True)

plt.subplot(3, 1, 3)
for i, zeta in enumerate(damping_ratios):
    plt.plot(frequency_ratios, response_factors_acceleration[i], label=f'Damping Ratio {zeta:.2f}')
plt.title('Acceleration Response Factor')
```

```python
plt.xlabel('Frequency Ratio (\u03c9/\u03c9n)')
plt.ylabel('Acceleration Factor')
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()
```



In [6]:

```python
# Calculate and plot Transmissibility
transmissibility_force = []

for zeta in damping_ratios:
    tf = []  # Force transmissibility for this damping ratio
    for r in frequency_ratios:
        numerator = 1 + (2 * zeta * r)**2
        denominator = (1 - r**2)**2 + (2 * zeta * r)**2
        tf.append(np.sqrt(numerator / denominator))
    transmissibility_force.append(tf)

# Plot Transmissibility
plt.figure(figsize=(10, 6))

for i, zeta in enumerate(damping_ratios):
    plt.semilogx(frequency_ratios, transmissibility_force[i], label=f'Damping Ratio {zeta:.2f}')

plt.title('Force and Ground Motion Transmissibility')
plt.xlabel('Frequency Ratio (\u03c9/\u03c9n)')
plt.ylabel('Transmissibility')
plt.legend()
plt.grid(True, which="both", linestyle='--')
plt.show()
```


Force and Ground Motion Transmissibility
Damping Ratio 0.01
Damping Ratio 0.02
Damping Ratio 0.03
Damping Ratio 0.04
Damping Ratio 0.05
Damping Ratio 0.06
Damping Ratio 0.07
Damping Ratio 0.08
Damping Ratio 0.09
Damping Ratio 0.10
Transmissibility
Frequency Ratio (ω/ωn)
50
40
30
20
10
0
10^{-1}
10^{0}

In [ ]: